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Stratigraphic variation across a Middle Devonian to Mississippian rift-basin margin and implications for subsequent fold and thrust geometry, northeastern Brooks Range, Alaska

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A

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STRATIGRAPHIC VARIATION
ACROSS A MIDDLE DEVONIAN TO MISSISSIPPIAN RIFT-BASIN MARGIN
AND IMPLICATIONS FOR SUBSEQUENT FOLD AND THRUST GEOMETRY,
NORTHEASTERN BROOKS RANGE, ALASKA

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ABSTRACT

A stratigraphic record from the eastern Brooks Range, Alaska, is interpreted to represent erosion and deposition of syn-rift and post-rift terrigenous clastic rocks across a Middle Devonian - Mississippian rift-basin margin. Middle Devonian - Mississippian terrigenous clastic rocks unconformably overlie complexly deformed Romanzof chert and constrain the age of latest mid-Paleozoic contractional deformation to pre-Middle Devonian time. The succession forms an abruptly southward-thickening basin-margin wedge characterized by abrupt facies changes, local evidence of active tectonism, multiple unconformities merging northward toward the basin margin, locally derived clastic deposits. The oldest deposits of this wedge are Middle - Upper(?) Devonian shallow-marine to alluvial-fan deposits (Ulungarat formation). Algal limestone with intercalated terrigenous clastic deposits and plant fossils (Mangaqtaaq formation) locally overlies the Ulungarat formation. The Ulungarat and Mangaqtaaq formations are interpreted to record syn-rift deposition.

Coastal-plain to marine deposits of transgressive Kayak Shale overlie and intertongue with retrogradational Kekiktuk Conglomerate, recording coastal retreat and drowning of low-energy paleoshoreline. Deposits of the retrogradational Kekiktuk fluvial system thin and fine upward and to the north, reflecting depositional onlap of the basin-margin high. Kekiktuk Conglomerate and Kayak Shale are interpreted to overlie the post-rift unconformity and record the beginning of thermal subsidence.

This stratigraphic succession provides a spatial and genetic link between structurally separated, stratigraphically distinct rocks of the Endicott Group. Thick,

allochthonous rocks to the south record progradation and eventual retrogradation of a basin-filling wedge, whereas thin, autochthonous rocks to the north record transgressive overlap of the basin-margin sediment source area.

The structural boundary between the north-central and northeastern Brooks Range coincides with the mid-Paleozoic rift-basin margin. North-vergent duplexes beneath the Kayak Shale consist of horses in the Middle Devonian-Mississippian clastic wedge to the south and thicker horses in pre-Middle Devonian rocks to the north. Above the Kayak Shale, north-vergent thrust-truncated folds are succeeded northward by detachment folds. These structural characteristics reflect the combined influence of abrupt lateral changes in stratigraphy across the rift-basin margin and stratigraphically controlled vertical variations in structural behavior.

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1. INTRODUCTION

This study documents a stratigraphic record interpreted to represent erosion and deposition of syn-rift and post-rift terrigenous clastic rocks across a Middle Devonian to Mississippian rift-basin margin in northeastern Alaska. The stratigraphic succession is part of a basinward-thickening terrigenous clastic wedge. The coarse-grained nonmarine deposits of the wedge prograded basinward then retrograded as a marine transgression flooded the wedge, raising regional base level and confining coarse clastic deposition to the earlier source area. Detailed structural and stratigraphic studies and a new invertebrate fossil collection constrain the timing and character of a change in tectonic setting from contractional deformation to onset of deposition of a regional rift to passive continental-margin succession. This study improves the previously limited understanding of this change and the lateral relationships of the Devonian to Mississippian terrigenous clastic rocks at the base of the rift to passive-margin succession.

Middle Devonian to Mississippian rocks in the upper Kongakut River region record a period of geologic history whose record is missing elsewhere in the northeastern Brooks Range and thus provide critical information about the timing of the transition from a contractional orogen to a rift to passive margin setting. This succession is also important because it occupies a geographic position between and provides critical information about the relationship between two distinct allochthonous and autochthonous successions of regionally extensive Devonian to Mississippian terrigenous clastic rocks. Regional stratigraphic variations within these rocks are interpreted to reflect different positions across the rift-basin margin.

This research also documents how the geometry of the rift-basin margin and the variations in stratigraphy across it influenced structural style as the Brooks Range fold and thrust belt propagated landward across the middle Paleozoic tectonic hinge during Late Cretaceous(?) to Cenozoic time. Detailed structural studies show that changes in the stratigraphic succession, including the geometry of the basinward-thickening clastic wedge, correspond with changes in structural style. An additional significant structural control may have been reactivation of rift-basin margin normal faults as thrust faults and/or upward deflection of thrust faults by the steeply dipping footwalls of normal faults.

2. REGIONAL GEOLOGIC SETTING

2.A. DEVONIAN TO MISSISSIPPIAN REGIONAL STRATIGRAPHY

2.A.1. The Ellesmerian Sequence

The Ellesmerian Sequence of northern Alaska (Lerand, 1973; Grantz et al., 1981) is interpreted to be the depositional record of a mid-Paleozoic to Early Cretaceous south- to southwest-facing passive continental margin (Dutro, 1981; Moore et al., 1992). As defined by Lerand (1973), Grantz et al. (1981), and Hubbard et al. (1987), the Ellesmerian Sequence is a tectonostratigraphic sequence that records a complete cycle of basin evolution. As originally defined and used herein, the Ellesmerian Sequence is the depositional record of a long and complex phase in the tectonic evolution of northern Alaska. It is not a single "sequence" as defined in a stratigraphic sense (Van Wagoner et al., 1988), but rather includes multiple unconformity-bounded sequences (e.g. Hubbard et al., 1987). The boundaries of the Ellesmerian Sequence reflect major changes in tectonic regime. Polydeformed rocks unconformably underlie little-deformed rocks of the Ellesmerian Sequence. The character and timing of this tectonic transition are poorly understood because the Middle to Late Devonian part of the record is missing throughout most of the northeastern Brooks Range and North Slope.

The rocks that underlie the Ellesmerian Sequence are a lithologically heterogeneous assemblage of low-grade metasedimentary and metavolcanic rocks that are locally intruded by Devonian granites (Dillon et al., 1987b; Grantz et al., 1990). Multiple generations of folds, faults, and penetrative structures characterize this underlying assemblage. This polydeformed assemblage records the last major mid-Paleozoic contractional deformation in Arctic Alaska, which has generally been assumed to be coeval with the Late Devonian to Early Mississippian Ellesmerian orogeny of the Canadian Arctic Islands (Lerand, 1973; Grantz et al., 1981; Hubbard et al., 1987). Based on this assumption, Devonian to Mississippian terrigenous clastic rocks in northern Alaska previously have been assumed to be syn-orogenic deposits (Nilsen, 1981; Brosge et al., 1988).

In the North Slope subsurface, Grantz and May (1988) recognized an early stage of graben-fill deposition at the base of the Ellesmerian Sequence. They named this graben-filling stage the Eo-Ellesmerian ("Eo" meaning "earliest subdivision" (Webster's Third New International Dictionary)) because on seismic-reflection lines the deposits are separated from overlying deposits by an unconformity with only slight angular discordance and do not share the polydeformational history recorded in underlying rocks. The Eo-Ellesmerian is defined by its basal position and depositional setting in normal fault-bounded basins.

2.A.2. The Endicott Group

Upper Devonian to Lower Mississippian terrigenous clastic rocks crop out along the entire east-west axis of the Brooks Range and are recognized in the North Slope subsurface (fig. 2.1). Tailleur et al. (1967) named this succession of shale, sandstone, and conglomerate in the central Brooks Range the Endicott Group and extended the definition to include the Kekiktuk Conglomerate in the northeastern Brooks Range. Mull et al. (1976) and Nilsen (1981) recognized two distinct stratigraphic successions within the Endicott Group, a thin autochthonous succession to the north and a thick allochthonous

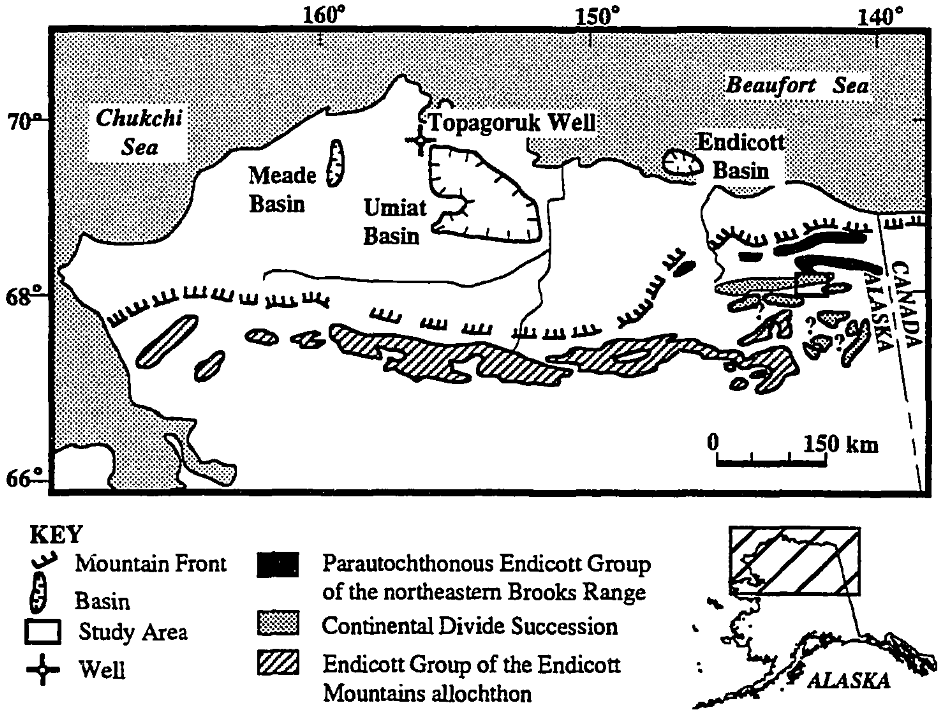


Figure 2.1. Generalized geologic map of northern Alaska showing outcrop exposures of Middle Devonian to Mississippian terrigenous clastic rocks in the northern Brooks Range and coeval basins in the subsurface to the north. Map adapted from Brosge et al. (1988), their figure 14.1.

succession to the south (fig. 2.2). The two successions are distinguished by differences in thickness, stratigraphic succession, age range, and the presence of a major angular unconformity at the base of the autochthonous succession. The top of the Endicott Group in both successions is formed by the transgressive Kayak Shale, which in each succession gradationally underlies platform carbonate rocks of the Lisburne Group (Bowsher and Dutro, 1979; Brosge et al., 1962; Tailleur et al., 1967).

The allochthonous Endicott Group was deposited south of the autochthonous Endicott Group, but was displaced northward during the Jurassic to Cenozoic Brookian orogeny. The original paleogeographic and depositional relationship between the two successions and their tectonic setting of deposition are poorly understood and unclear as a result of Brookian deformation. Tailleur et al. (1967), Nilsen and Moore (1984), and Brosge et al. (1988) suggested that the autochthonous and allochthonous Endicott successions were genetically related, but noted that major thrust faults at the base of the allochthonous succession make correlations difficult.

2.A.2.a. Allochthonous Endicott Group

The Endicott Group in the allochthonous succession is a progradational-retrogradational terrigenous clastic succession 4000^{+} m thick (Nilsen and Moore, 1984) (fig. 2.2). It is exposed within the Brooks Range in thrust sheets that form the Endicott Mountains allochthon (Mull et al., 1976). Beneath the Endicott Group, the upper Middle to lower Upper Devonian (Givetian to Frasnian) Beaucoup Formation (Dutro et al., 1979) unconformably overlies the Skajit Limestone (Dillon et al., 1987a) and is gradationally overlain by the Hunt Fork Shale (Dutro et al., 1979). The Beaucoup Formation has not been included in the Endicott Group, but it is included for discussion here because it

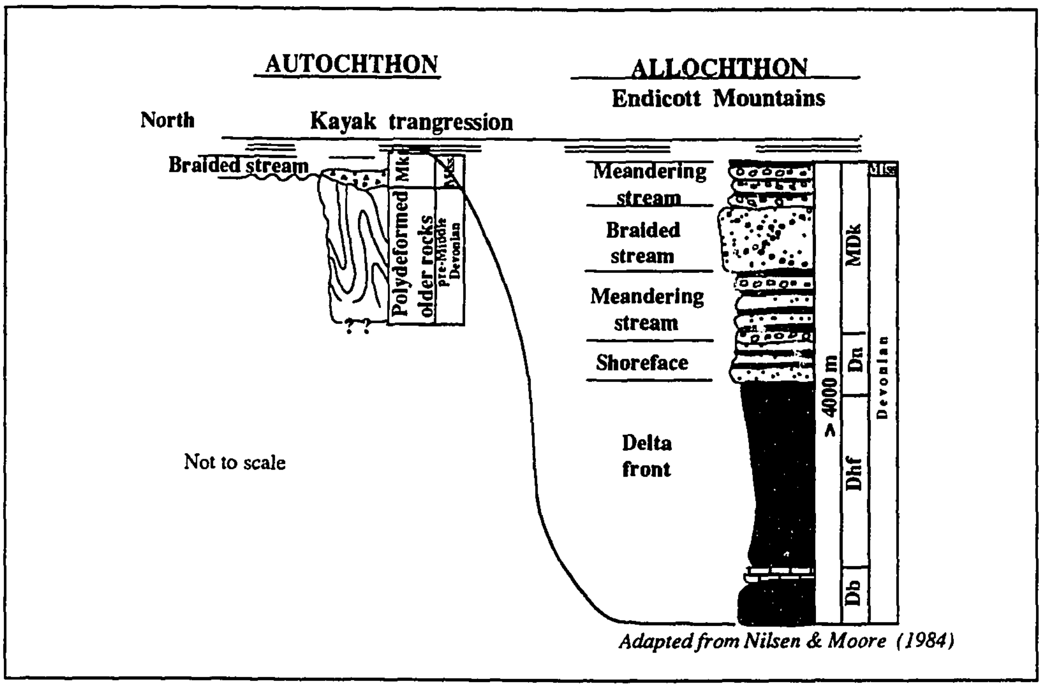


Figure 2.2. Generalized stratigraphic columns showing depositional setting for the two successions of Middle Devonian to Mississippian terrigenous clastic rocks. Allochthonous succession: Beaucoup Formation (Db), Hunt Fork Shale (Dhf), Noatak Sandstone (Dn), and Kanayut Conglomerate (MDk). Autochthonous succession: Kekiktuk Conglomerate (Mkt). The Kayak Shale overlies both successions.

grades upward into the Hunt Fork Shale, the lowest unit of the Endicott Group. The Beaucoup Formation is a heterogeneous marine assemblage that includes shallow-marine limestone, deep-marine shale, volcaniclastic rocks, sandstone, and local conglomerate with a composition similar to that of overlying formations (Dutro et al., 1979; Anderson, 1987, Dillon et al., 1987a). As discussed by Moore et al. (1992) and Dillon (1989), the Beaucoup Formation is structurally disrupted and includes abrupt facies changes and/or unrelated thrust slivers.

The Upper Devonian to Lower Mississippian(?) allochthonous Endicott Group includes, from base upwards, slope to prodelta Hunt Fork Shale (Upper Devonian, (Frasnian to Famennian)) (Chapman et al., 1964), marginal-marine Noatak Sandstone (Upper Devonian) Famennian)) (Dutro, 1952), meandering and braided fluvial systems of the Kanayut Conglomerate (Upper Devonian (Famennian) to Lower Mississippian(?)) (Bowsher and Dutro, 1957; Nilsen and Moore, 1984), and transgressive marine Kayak Shale (Bowsher and Dutro, 1957). This succession has been interpreted to record southwestward progradation of a major fluvial-dominated deltaic system followed by marine transgression (Nilsen and Moore, 1984). This interpretation is supported by facies relations, decreasing clast size toward the southwest, paleocurrent data, and clast composition indicating a chert-rich highland to the northeast (Nilsen and Moore, 1984). Woidneck et al. (fig. 5, 1987) suggested that sandstones in the lower Kayak that are regarded as channel-mouth bars may be distal equivalents of the autochthonous Kekiktuk Conglomerate. To the north, the base of the allochthonous Endicott Group is considered to be a thrust fault below the Hunt Fork Shale. Dillon (1989) interpreted Hunt Fork Shale exposed to the south to overlie a regional unconformity or locally to grade upward from the underlying Beaucoup Formation.

2.A.2.b. Autochthonous Endicott Group

The Mississippian Endicott Group is autochthonous in the subsurface of the North Slope and is parautochthonous in the northeastern Brooks Range and in structural windows in the southern Brooks Range. The succession is less than 600 m thick and consists mostly of the Mississippian (Visean) Kekiktuk Conglomerate and Kayak Shale (fig. 2.2). In the North Slope subsurface, normal fault-bounded basins are filled with up to 4,000 m of unmetamorphosed, Middle Devonian and Mississippian non-marine terrigenous clastic deposits containing coal and plant fossils (Kirschner and Rycerski, 1988; Grantz et al., 1990). The geometry of the basin fill on seismic reflection lines suggests a system of half-grabens (Kirschner and Rycerski, 1988; Grantz et al., 1990). These Mississippian basin-fill deposits are assigned to the Eo-Ellesmerian stage of the Ellesmerian Sequence (Grantz and May, 1988) and to the Endicott Group (Grantz and May, 1988; Grantz et al., 1988; Kirschner and Rycerski, 1988). However, the Devonian rocks are poorly understood and their interpretation and assignment to the Endicott Group are uncertain (Grantz et al., 1988; Brosge et al., 1988; Kirschner and Rycerski, 1988; Grantz et al., 1990).

2.A.2.b.1. Middle Devonian rocks in the North Slope subsurface

Middle Devonian rocks are present below 10,040 ft in the Topagoruk #1 well in the National Petroleum Reserve Alaska (Collins, 1958) (fig. 2.1). The succession is more than 180 m thick and is composed of upward-fining intervals of cross-stratified chert pebble conglomerate, pebbly sandstone, and coarse- to fine-grained sandstone. These conglomerate and sandstone intervals are interbedded with dark-gray carbonaceous shale and claystone. Interbedded plant fragments are of Middle (Early?) Devonian age

(Collins, 1958). Based on inclined laminae in bedding, Collins (1958) reported down-hole dips within the Devonian rocks that vary between 35° and 60°. Based on these dips, this succession has been interpreted as being tightly folded and cited as evidence of Late Devonian orogeny in northern Alaska (Grantz et al., 1990).

Because of its relevance to the age of mid-Paleozoic deformation, I examined core from the Topagoruk #1 well to clarify relationships described by Collins (1958). In typical cross-stratified deposits, depositional horizontal is best approximated by the most gently dipping cross-laminae, rather than the coarse-grained trough cross-stratified deposits at the base of upward-fining conglomerate and sandstone cycles. Applying this criterion to the cross-stratified sandstone beds in the Topagoruk #1 well, the dip of depositional horizontal is between 12° and 24° (fig. 2.3). Shale and claystone interbedded between the conglomerate and sandstone deposits show dips varying from subhorizontal to 60°. However, core 90 at 10,433 ft contains shale and claystone with convoluted laminations interpreted by Collins (1958) to reflect contemporaneous slumping. This suggests that other anomalously steep dips reported for the shale and claystone may be related to slumping. The gentle dips of the interbedded conglomerate and sandstone deposits support this conclusion. These data indicate a low-angle discordance with the overlying red beds, but the exact nature of the contact is unclear. The contact may be an unconformity with a low-angle discordance, perhaps caused by tilting of fault blocks. This succession clearly lacks the penetrative structures that characterize the majority of the lower Paleozoic rocks throughout the North Slope subsurface and northeastern Brooks Range.

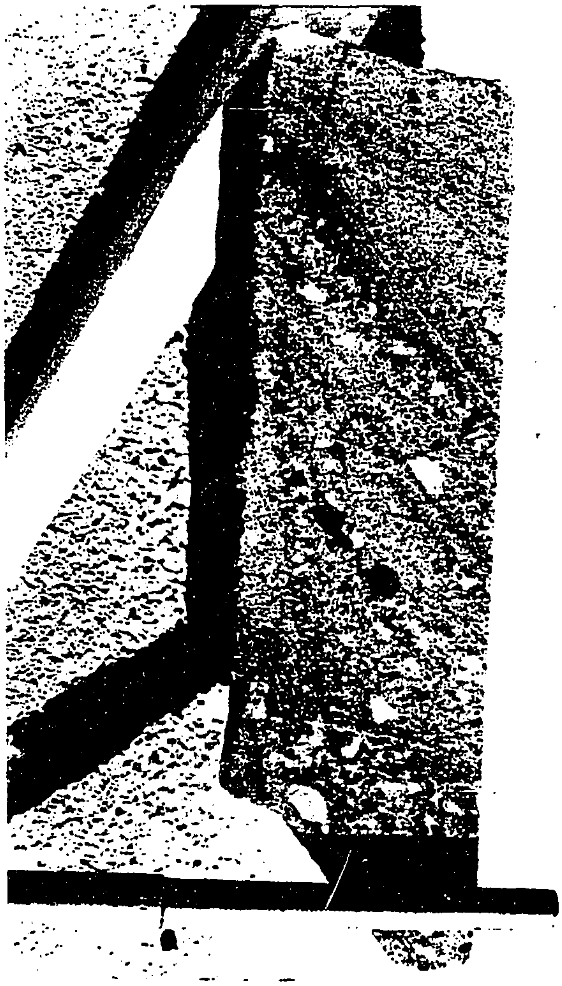


Figure 2.3. Cross-bedded conglomerate and sandstone from core #85 (10,228 ft) in the Topagorak #1 well. The dip of depositional horizontal is best approximated by the gentle dip of cross-strata at the top of the fining-upward cycle. Pen for scale.

Vitrinite reflectance values from the Topagoruk #1 well are 1.18 for Devonian strata, 1.12 for the overlying red beds of unknown age, 1.08 for the Permian to Triassic Sadlerochit Group, and 1.02 for the Triassic Shublik Formation (Magoon and Bird, 1988). These thermal data define a gradual subsidence/burial curve. Lack of penetrative strata and structures, major angular discordance, or thermal discordance suggest a structural and thermal history for the Middle Devonian that is not significantly different from overlying strata. On this basis, I interpret this succession to overlie and post-date polydeformed strata and to be part of the Eo-Ellesmerian graben-fill succession.

2.A.2.b.2. Mississippian Endicott Group in the North Slope subsurface

In the subsurface at the Endicott field near Prudhoe Bay (fig. 2.1), the Kekiktuk Conglomerate is described by Woidneck et al. (1987) and Melvin (1987) as an upward-fining succession of conglomerate, sandstone, and shale with interbedded coal. The formation is up to 500 m thick, but is laterally discontinuous and shows great variability in thickness. Deposition of the formation was locally controlled by syndepositional down-to-the-southwest normal faulting (Woidneck et al., 1987). The formation in the Prudhoe Bay area unconformably overlies deformed and weakly metamorphosed argillite and quartzite (Hubbard et al., 1987) and grades vertically and laterally into Kayak Shale or, locally, the Itkilyariak Formation (Mull and Mangus, 1972; Woidneck et al., 1987). Grantz and May (1988) assigned the Endicott Group in the North Slope subsurface to the Eo-Ellesmerian.

Based on palynological data, Ravn (1991) assigned a Mississippian (?late Tournaisian/earliest Visean to earliest late Visean) age to the Kekiktuk at the Endicott field. On the basis of age, the Kekiktuk in the subsurface of the Prudhoe Bay area may be correlative with the basal sandstone member of the Kayak Shale in the Endicott Mountains allochthon (Woidneck et al., 1987).

2.A.2.b.3. Mississippian Endicott Group in the northeastern Brooks Range

Parautochthonous, Mississippian (Visean) Kekiktuk Conglomerate and overlying Kayak Shale crop out in the northeastern Brooks Range from the range front to just north of the continental divide (fig. 2.1). The Kekiktuk Conglomerate unconformably overlies multiply deformed Precambrian to lower Paleozoic metasedimentary and metavolcanic rocks with generally high-angle discordance. The Kekiktuk Conglomerate is laterally discontinuous and generally less than 100 m thick, with deposition controlled by relief on the underlying unconformity surface. LePain (1993) interpreted the Kekiktuk Conglomerate to be a fining-upward succession of nonmarine debris-flow and fluvial deposits overlain by transgressive marine Kayak Shale deposited in paleovalleys in a rift-flank region.

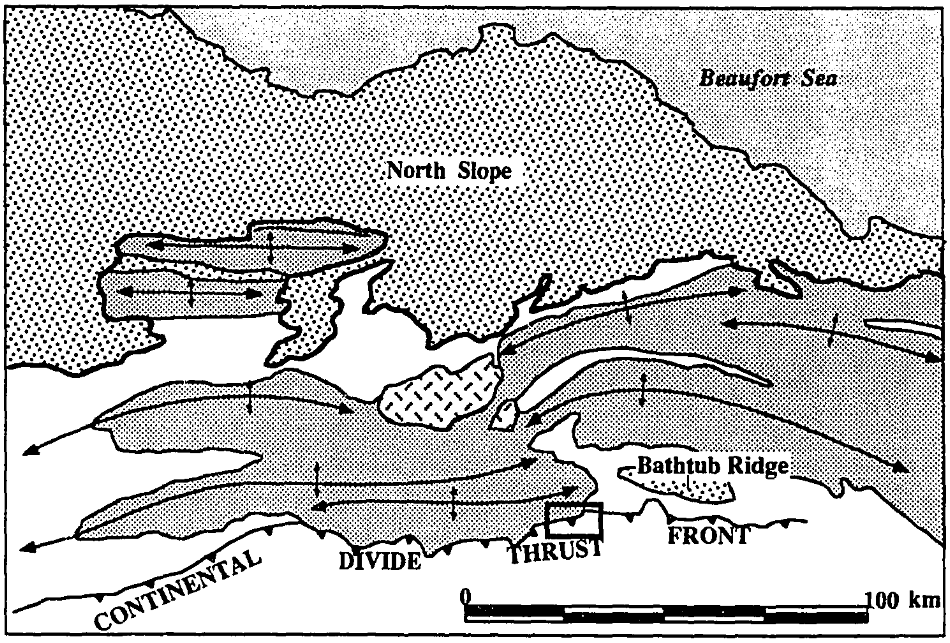
2.B. DEVONIAN TO MISSISSIPPIAN TECTONIC SETTING

Across northern Alaska, the character of the Devonian to Mississippian stratigraphic succession suggests deposition in a rift to passive-margin setting. Regional arguments for Devonian rifting include 1) contrast in deformation across the regional mid-Paleozoic angular unconformity (Grantz et al., 1990), 2) Middle Devonian to Mississippian extensional basins in the subsurface landward (north) of the inferred basin-margin (Grantz and May, 1988; Woidneck et al., 1987), 3) terrigenous clastic deposits below transgressive black shale and platform carbonates, 4) facies associated with major topographic relief and thickening toward the south and southwest (Moore et al., 1992), 5) lateral variability of facies over short distances with facies relationships that can be interpreted to reflect alternating basins and highs (Dutro et al., 1979; Hitzman et al., 1986; Mayfield et al., 1988), 6) syndepositional high-angle faulting (Hitzman et al., 1986; Moore et al., 1986; Woidneck et al.,1988), and 7) Devonian bi-modal volcanism in the southern Brooks Range (Dillon et al., 1980; Hitzman et al., 1986; Schmidt, 1987; Dillon, 1989). Regional arguments for an overlying passive-margin succession include 1) Devonian to Jurassic rocks of oceanic affinity (Murchey and Harris, 1985; Barker et al., 1988) form the highest thrust sheets of the Brooks Range and suggest an ocean basin to the south, 2) a Mississippian to Jurassic southward-thickening wedge with deeper-water facies to the south and southwest (Moore et al., 1992), and 3) basal deposits that can be interpreted as syn-rift deposits (Hitzman et al., 1986; Schmidt, 1987).

2.C. BROOKS RANGE STRUCTURE

The Brooks Range is a Late Jurassic and younger, north-vergent fold and thrust belt that extends east-west across Arctic Alaska. The northeastern Brooks Range is a younger salient protruding northward from the rest of the Brooks Range. This northeastern salient evolved by progressive northward migration of deformation and uplift during the Cenozoic (O'Sullivan et al., 1993) as a result of crustal shortening interpreted to be on the magnitude of 10's of kilometers (Wallace and Hanks, 1990).

A major structural boundary, the "continental divide thrust front", separates two distinct structural provinces in the eastern Brooks Range (fig. 2.4) (Wallace et al., 1988; Wallace and Hanks, 1990). To the south, the main east-west axis of the Brooks Range is an area of complex, closely spaced north-vergent folds and thrust faults in Middle Devonian and younger rocks. These structures formed mainly during the Late Jurassic to



Regional anticlinoria cored by pre-Middle Devonian rocks

Devonian Okpilak Batholith and Jago Stock

Middle Devonian to Lower Cretaceous rocks, Ellesmerian Sequence includes Eo-Ellesmerian

Lower Cretaceous to Cenozoic foredeep deposits

Box shows study area

Range front

Regional anticlinoria

Figure 2.4. Generalized geologic map of the northeastern Brooks Range showing regional anticlinoria, continental divide thrust front, and the study area.

Cretaceous part of the Brooks Range orogeny. The northeastern salient of the range is distinguished by major east-west trending, doubly plunging anticlinoria, that formed as a result of Cenozoic deformation. The anticlinoria are cored by pre-Middle Devonian rocks and overlain by detachment folds formed in Mississippian and younger rocks. The anticlinoria are interpreted to be the surface expression of horses in a regional duplex (Wallace and Hanks, 1990). The Kayak Shale, a shale horizon near the base of the Mississippian rocks, forms a major detachment horizon that is interpreted to be the roof thrust of the regional duplex and the detachment horizon for the overlying detachment folds. See Wallace and Hanks (1990) for a more detailed discussion of these relationships.

3. DEFINITION OF PROBLEM

3.A. DEVONIAN TO MISSISSIPPIAN ROCKS IN THE UPPER KONGAKUT RIVER REGION

Along the continental divide, in the upper Kongakut River region of the eastern Brooks Range (fig. 3.1), an unconformity-bounded unit of Middle(?) Devonian terrigenous clastic rocks was identified during reconnaissance mapping in the 1970's. This unnamed unit was mapped along two ridges near the headwaters of the Kongakut River and assigned a Middle Devonian(?) age based on shallow-marine fossils (unit Ds of Reiser et al., 1980). No detailed sedimentological or structural studies were conducted. The only written accounts of this unit are brief descriptions on the U.S. Geological Survey geologic map of the Demarcation Point quadrangle (Reiser et al., 1980) and by Brosge et al. (1981). The Middle (?) Devonian unit was interpreted to unconformably overlie complexly deformed older rocks and in turn to be unconformably overlain by the Kekiktuk Conglomerate (Reiser et al., 1980).

The existing reconnaissance mapping (Reiser et al., 1980) shows relationships exposed in this area that have considerable regional and scientific significance (fig. 2.4 and 3.1). The Middle Devonian rocks are exposed on the southeastern flank of a regional east-plunging anticlinorium, thus providing a well-exposed stratigraphic and structural section through pre-Middle Devonian to Mississippian rocks. Middle Devonian rocks are absent throughout the northeastern Brooks Range, so exposed rocks of this age, with a known fossil locality, provide an opportunity to fill an important gap in the rock record. Differences in geologic history across the unconformities below and above the Middle

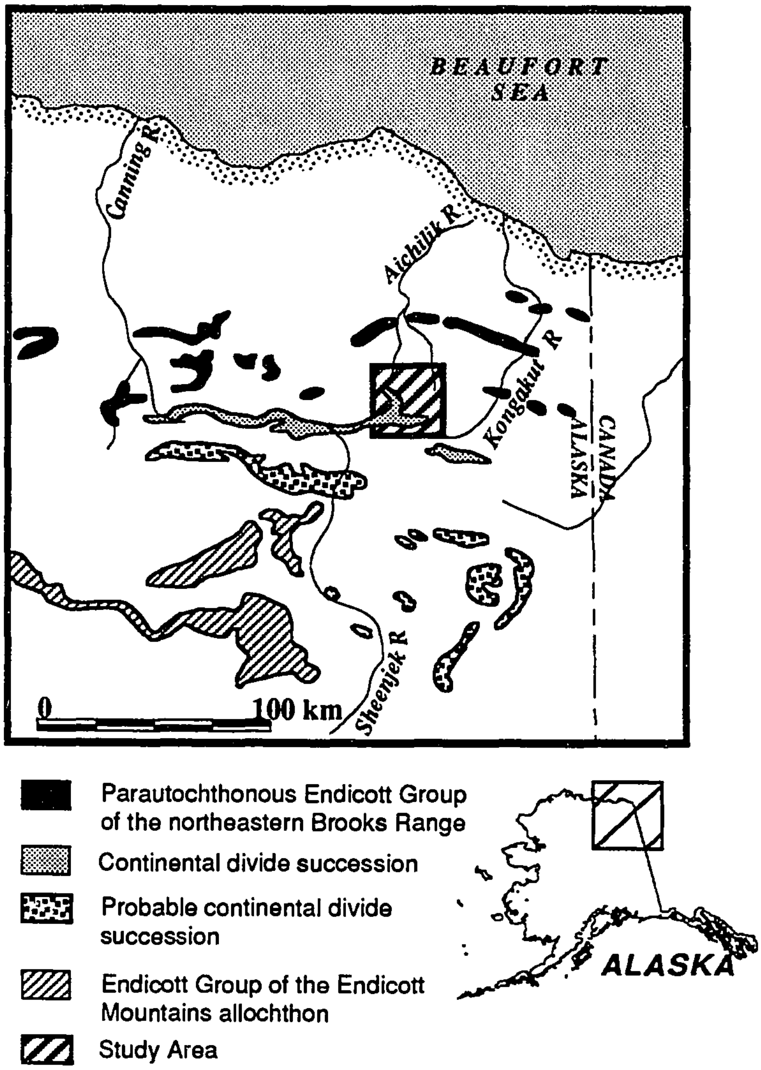


Figure 3.1. Generalized geologic map of the eastern Brooks Range showing distribution of Middle Devonian to Mississippian clastic rocks and location of the study area.

Devonian unit offer a basis for determining the timing and character of regional tectonic and depositional events, particularly the mid-Paleozoic transition from contractional deformation to rifting and passive-margin subsidence. The Middle Devonian unit is truncated northward beneath the sub-Kekiktuk unconformity, and the Middle Devonian and younger succession increases in thickness and other stratigraphic characteristics change southward from the vicinity of the truncation. The area occupies a geographic position between distinct parautochthonous and allochthonous successions of Devonian to Mississippian terrigenous clastic rocks, and thus is important for establishing the genetic and paleogeographic relationships between these successions. These important stratigraphic relationships coincide with the regional boundary between structures characteristic of the north-central and northeastern parts of the Brooks Range. The area allows the characterization of structures across this boundary and through a thick vertical section, and thus to determine the relationships between lateral and vertical variations in structure and stratigraphy. For these reasons, the upper Kongakut River region was chosen to be the focus of this study.

3.B. QUESTIONS ADDRESSED BY THIS STUDY

This research addresses a number of important questions based on what is known about the regional geology and the relationships exposed within the study area. These questions focus on Devonian to Mississippian tectonic and depositional setting and Mesozoic to Cenozoic structural evolution, and have served as guiding themes of the study. Progress made on addressing these questions is summarized in the final chapter of the dissertation (Chapter 17, Conclusions).

1) What was the depositional and tectonic setting during deposition of Middle Devonian to Mississippian terrigenous clastic rocks in the study area?

2) What are the differences in structural history across the unconformities in the Devonian to Mississippian stratigraphic successions?

3) What is the age of the latest mid-Paleozoic contractional deformation in northeastern Alaska?

4) How does the Middle Devonian to Mississippian stratigraphic succession in the study area fit into the regional depositional and tectonic history?

5) How does the character of the Middle Devonian to Mississippian stratigraphic succession change across the continental divide thrust front?

6) How do the character and geometry of Mesozoic to Cenozoic structures change across the continental divide thrust front?

4. LOCATION OF STUDY AREA AND METHODS OF STUDY

The study area is located at the headwaters of the Aichilik and Kongakut Rivers, southwest of Bathtub Ridge in the northeastern Brooks Range (fig. 3.1). This is in the Demarcation Point (A4) and Table Mountain (D4) quadrangles. The only work previously published on the area are the reconnaissance-scale maps of Reiser et al. (1980) and Brosge et al. (1976). The terrain is mountainous, up to 2200 m (7200 ft) in elevation. Local relief is up to 1130 m (3700 ft). Field work was conducted from remote spike camps during the 1988, 1989, 1990, and 1991 summer field seasons. For this study, detailed mapping at the scale of 1:25,000, analysis of minor structures, and measurement of stratigraphic sections were carried out to characterize the structural geometry and determine lateral variations in the stratigraphy of the field area. Study of sedimentary structures was conducted to determine environment of deposition and interpret depositional and tectonic paleogeography. Fossils were collected to constrain age relationships. Lithologic samples were collected for analysis of petrography, apatite fission tracks, palynology, vitrinite reflectance, and conodonts.

The primary data base for the interpretations presented here consists of a detailed geologic map (Plate 1) and a series of graphic columnar sections from 16 localities depicting the lithology, bedding character, and organization of the stratigraphic succession (Appendix H). These data are supplemented by conodont depostional age and thermal data (Appendix A), palynology depositional age and thermal data (Appendix B), shale vitrinite reflectance data (Appendix C), coal vitrinite reflectance data (Appendix D), apatite fission track data (Appendix E), point count data (Appendix F and G), and equal-area sterographic projections of structural data (Appendix I).

Chapter 16 is the complete text of Public Data File 93-77 published by the Alaska Division of Geological and Geophysical Surveys. There is some redundancy with other chapters as the Public Data File must stand alone as a separate paper.

5. LOCAL GEOLOGIC SETTING

North-vergent thrust faults divide the study area into major south-dipping thrust sheets (fig. 5.1; Plate 1). Two distinct stratigraphic successions are separated by the Aichilik pass thrust fault (fig. 5.2 and 5.3). To the north, in the footwall, thin laterally discontinuous Lower Mississippian Kekiktuk Conglomerate overlies complexly deformed Ordovician chert and phyllite across a high-angle unconformity. This thin Mississippian stratigraphic succession together with the underlying Romanzof chert is informally referred to here as the west fork valley succession (fig. 5.4). To the south, in the hangingwall, the Middle Devonian to Mississippian clastic succession is much thicker and includes two formations that are not present to the north (fig.5.5). This thicker Middle Devonian to Mississippian succession is here informally named the continental divide succession. Two thrust sheets within the continental divide succession, the Aichilik pass thrust sheet and the Kongakut River thrust sheet, have minor differences in thickness and organization.

Restoration of the continental divide succession to the south of the west fork valley succession shows that the Middle Devonian to Mississippian deposits form a southward-thickening clastic wedge. The Middle to Upper(?) Devonian Ulungarat formation is at the base of the continental divide succession. A low-angle unconformity marks the top of the formation. Locally, this unconformity is overlain by the Mangaqtaaq formation. The Kekiktuk Conglomerate overlies either the Mangaqtaaq formation or the Ulungarat formation with low-angle discordance, with underlying beds having slightly steeper south dips (fig. 5.1). In both successions, the Kekiktuk Conglomerate is overlain .

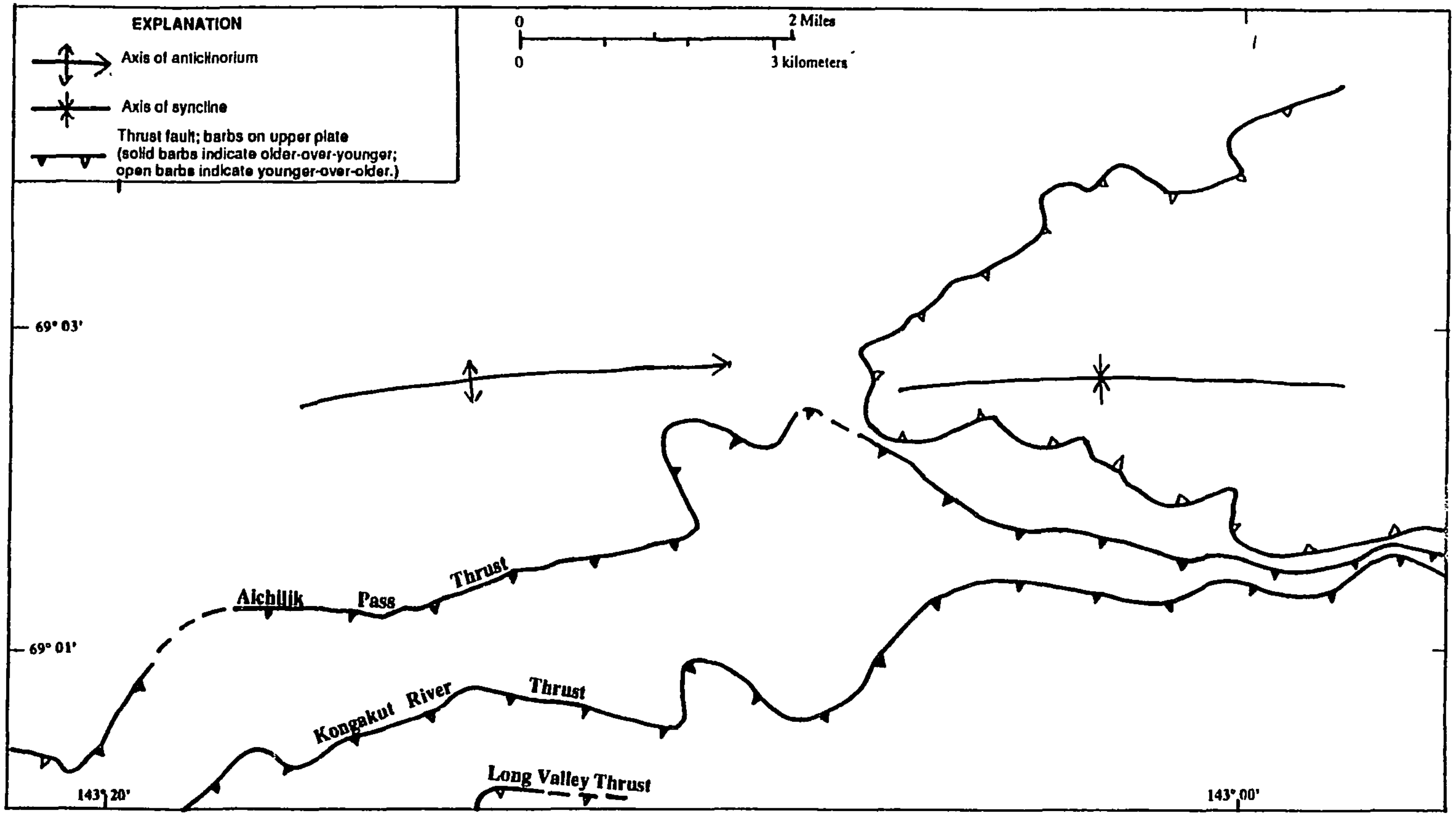
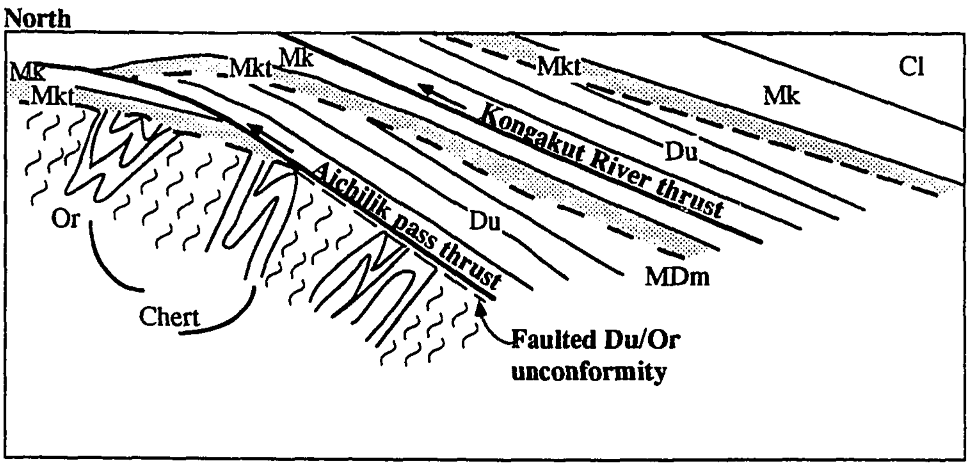


Figure 5.1. Simplified map of study area showing trace of major thrust faults.



KEY

— — —	Unconformity
Thrust fault	
Bedding	

Cl	Lisburne Group
Mk	Kayak Shale
Mkt	Kekiktuk Conglomerate
MDm	Mangaqtaaq formation
Du	Ulungarat formation
Or	Romanzof chert

Figure 5.2. Schematic cross-section illustrating north to south stratigraphic relationships and structural geometry across the Aichilik pass and Kongakut River thrust faults.

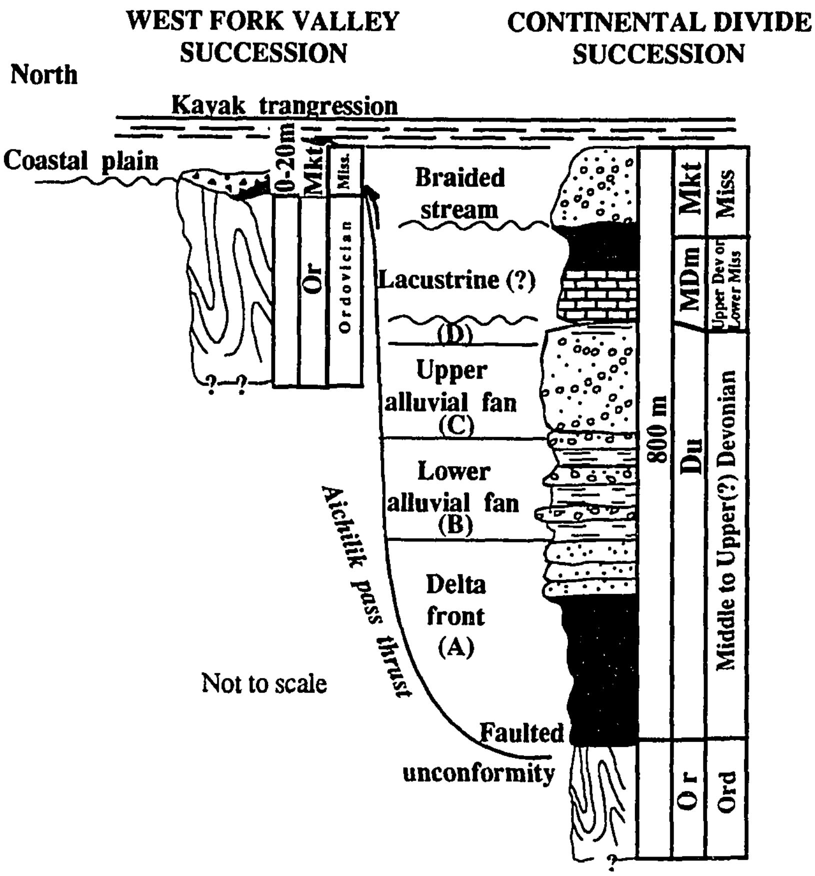


Figure 5.3. Generalized columns illustrating stratigraphic sequence exposed in the study area showing differences in stratigraphy and depositional environments with abrupt southward increase in thickness of Middle Devonian to Mississippian clastic rocks across the Aichilik pass thrust. Estimated displacement across the Aichilik pass thrust varies from a few hundred meters to 2 km. The succession includes Romanzof chert (Or), Ulungarat formation (Du), Mangaqtaaq formation (MDm), and Kekiktuk Conglomerate (Mkt).

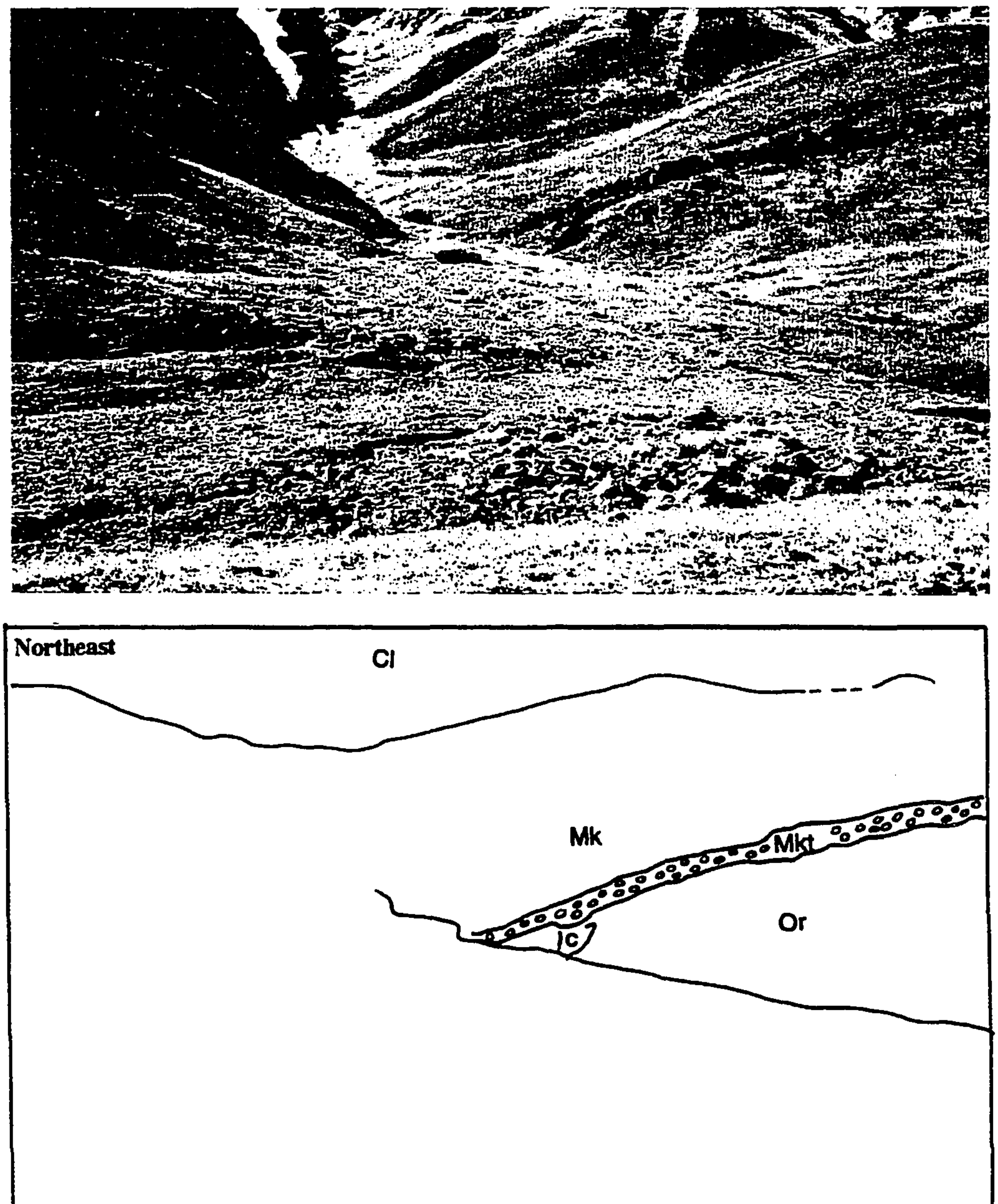


Figure 5.4. View toward southeast near headwaters of the Aichilik River, showing west fork valley succession. Line drawing shows geologic relationships. Caribou for scale. Romanzof chert (Or), bedded chert within Romanzof chert (c), Kekiktuk Conglomerate (Mkt), Kayak Shale (Mk), Lisburne Group (Cl).

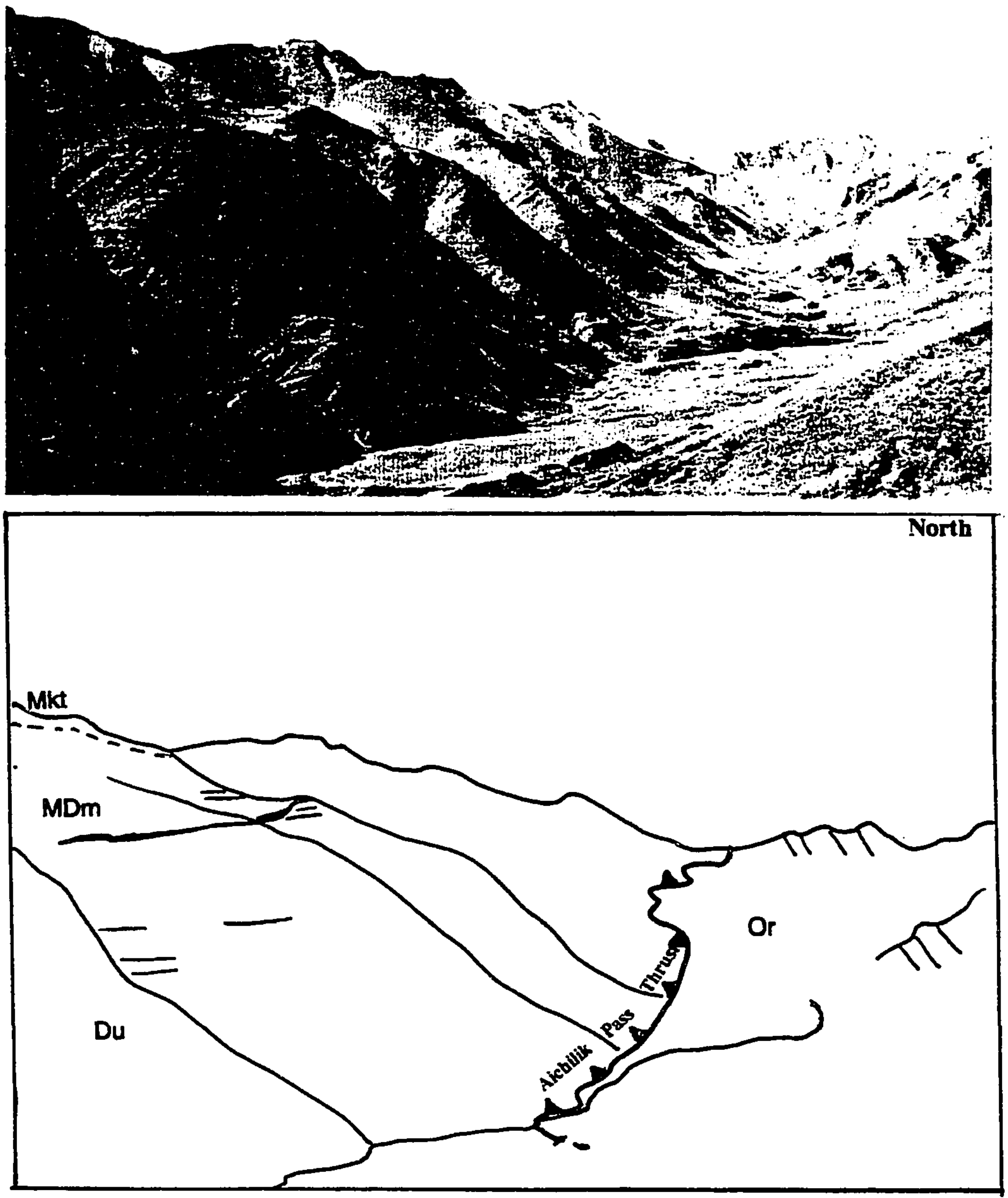


Figure 5.5. View to west showing continental divide succession thrust northward over the west fork valley succession. Middle Devonian to Mississippian rocks dip south, lenses of Romanzof chert dip north. Line drawing shows geologic relationships. Local relief is 600 m. Aichilik pass thrust (APT), Romanzof chert (Or), Ulungarat formation (Du), Mangaqtaaq formation (MDm), and Kekiktuk Conglomerate (Mkt).

by the Mississippian Kayak Shale and the Mississippian to Pennsylvanian Lisburne Group.

In the western part of the study area, the Aichilik pass thrust displaces the Middle Devonian Ulungarat formation along the contact with the Ordovician Romanzof chert (Plate 1). To the east, the Aichilik pass thrust cuts stratigraphically higher in the footwall, successively displacing the hangingwall succession over Kekiktuk Conglomerate and Kayak Shale. Thrust overlap and truncation of contacts indicate that displacement across the Aichilik pass thrust is between a few 100's of m and 1 or 2 km. The Middle Devonian to Mississippian rocks lack the strong polydeformational fabric that characterizes the Ordovician chert and phyllite in the area. The relatively small displacement coupled with the difference in structural history suggest that the Ulungarat formation originally overlay the Ordovician Romanzof chert across an angular unconformity. The younger over older relationship to the west is interpreted to reflect faulting along this unconformity (fig. 5.1). Low-angle discordances within the Middle Devonian to Mississippian succession are interpreted as internal unconformities reflecting tilting during deposition. Cretaceous(?) to Tertiary structures are consistent in character and orientation throughout the succession.

6. ROMANZOF CHERT

6.A. DESCRIPTION

The Romanzof chert (informal name) consists of massive and bedded chert lenses in phyllite (Reiser, et al, 1980; Anderson, and Wallace 1991). The phyllite matrix constitutes about 40 - 60% of the assemblage. This is the stratigraphically and structurally lowest unit in the area, but it forms topographic highs due to resistance of the chert to erosion. The top of the assemblage is a high-angle discordance beneath unconformably overlying strata. Stratigraphic thickness of the unit is unknown both because the base is not exposed and because of structural thickening. Structural thickness is greater than 1000 m. Chert lenses or groups of lenses form mappable linear features that extend for kilometers in an east-west orientation (Plate 1). Individual chert lenses extend for up to 100's of meters and are laterally discontinuous. The nature of the contacts between the chert and phyllite is unknown, but the assemblage probably represents folding and fault imbrication of a few intervals of chert and phyllite.

The massive to bedded cherts are black, various shades of gray, and white. Abundant radiolarian ghosts are visible in thin-section. Micro-fractures within the chert are filled with equant quartz crystals. Locally, vertical to subvertical mm-diameter burrows extend inward from knobs on chert bedding surfaces. The chert lenses are complexly deformed internally. Bedding and cleavage are steep to subvertical. The cherts display at least two generations of tight to isoclinal folds with variably plunging refolded axes. Locally, these folds are offset by thrust faults. In most cases, vergence is indeterminable, but in at least one place north-vergence was determined. The axial surfaces of the folds and the associated thrust faults were rotated to steep dips prior to formation of the overlying regional unconformity.

Black phyllite is present between the chert lenses. The original depositional character of the phyllite is unclear as no bedding is preserved. Cleavage is steep to subvertical. Intensely sheared zones are locally present.

6.A.1. Unconformity Surface Truncating the Romanzof Chert

Major chert lenses and the folds and faults within them are steep to subvertical and are truncated by the overlying unconformity surface. Resistant chert knobs create as much as 5 m of relief on the unconformity surface. This relief may be erosional, caused in part by the difference in resistance to erosion between chert and phyllite, and/or may be the result of high-angle faulting just before and/or during deposition of the unconformably overlying Kekiktuk Conglomerate, as discussed below. To the north, in the west fork valley succession, the unconformity is overlain by the Mississippian Kekiktuk Conglomerate. To the south, beneath the continental divide succession, the unconformity is interpreted to have been overlain by the Middle to Upper(?) Devonian Ulungarat formation, although the contact is now a low-displacement (100's m) thrust fault (fig.5.1).

6.B. AGE

The Romanzof chert is of probable Ordovician age. Reiser et al. (1980) assigned an inferred Ordovician-Cambrian age to this chert and phyllite unit. Moore and Churkin (1984) and Moore et al. (1992) reported Ordovician graptolites recovered from presumably equivalent rocks along strike to the southwest in the Arctic quadrangle. The abundance of radiolarians indicates the unit is no older than Ordovician because the earliest known bedded radiolarian cherts are Ordovician (Jones and Murchey, 1986)

6.C. DEPOSITIONAL SETTING

The original depositional relationship between the chert and the phyllite is unclear. The chert and the phyllite may have been interbedded and/or laterally equivalent. Alternatively, they may be from different depositional settings, but were structurally juxtaposed later. Graptolites associated with black phyllite and bedded radiolarian chert both indicate a deep basinal depositional setting. Jones and Murchey (1986) reported that bedded radiolarian chert associated with continental margins is generally black and gray. Thus, the color of the Romanzof chert suggests deposition on or near a continental margin.

7. ULUNGARAT FORMATION

The Middle to Upper(?) Devonian Ulungarat formation (informal name) is a coarsening- and thickening-upward, terrigenous clastic succession that is 394 m thick at the type section (fig. 7.1, Appendix H). The unit is well-exposed in the headwaters region of the Kongakut River. The type section is exposed in a north-flowing drainage at the east end of Ulungarat Ridge (new name) in the NW1/4 of Section 7, T.5S., R.38E., Demarcation Point (A-4) quadrangle (69° 1.6' N, 143° 10.6' W) (Locality A, Plate 1; Appendix H). Ulungarat is an Inupiat Eskimo word meaning "sloping ridge with one very steep side" (J. Nageak, University of Alaska Fairbanks, personal communication, 1989), which describes the type locality. A native Alaskan name is appropriate because this area is within the traditional hunting ground of the Inupiat Eskimo.

In the study area, the base of the formation is defined by thrust faults which place the Ulungarat formation over the Ordovician Romanzof chert, the Mississippian Kekiktuk Conglomerate, or Mississippian Kayak Shale in different places. As discussed above, the contact between the Ulungarat formation and the Romanzof chert along the Aichilik pass thrust is interpreted to be a faulted unconformity, based on differences in deformation history, and the age relationships and relatively low displacement across the fault. The upper contact of the Ulungarat formation is marked by an observed discordance of less than 5°, with underling beds having slightly steeper south dips. This surface locally truncates, or is offset by, possible high-angle faults. The upper members of the Ulungarat formation are truncated laterally beneath this surface suggesting erosion prior to deposition of overlying formations. Locally, the Ulungarat formation is overlain by the

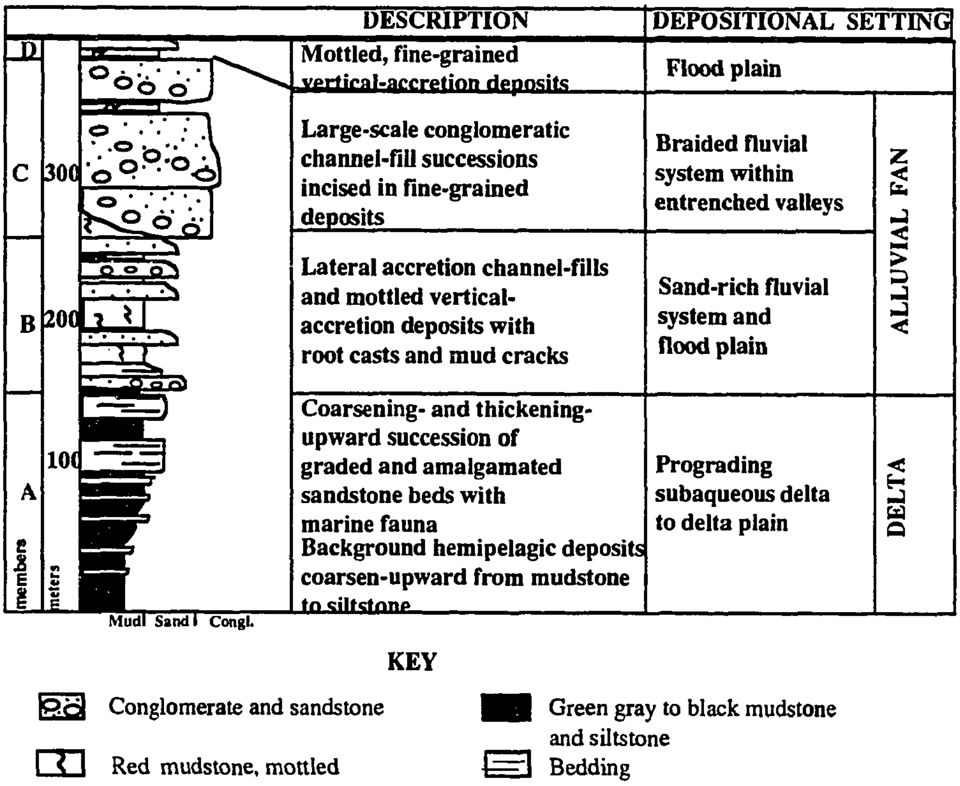


Figure 7.1. Generalized stratigraphic column for the Ulungarat formation. Refer to Appendix H for detailed graphic columns of measured sections.

informally named Upper Devonian to Lower Mississippian Mangaqtaaq formation (Anderson and Watts, 1992). Elsewhere, the Ulungarat formation is unconformably overlain by the Lower Mississippian Kekiktuk Conglomerate. On the basis of variations in lithology and internal organization, the Ulungarat formation is divided into four informal members, labeled from base to top, A, B, C, and D (fig. 7.1).

7.A. STRATIGRAPHIC SUCCESSION

7.A.1. Member A

7.A.1.a. Description of member A

Member A is a fine-grained, upward-coarsening succession of fossiliferous mudstone to siltstone with sandstone interbeds increasing in thickness and abundance upward (fig. 7.1). At the type section (locality A, Plate 1; Appendix H, measured section 90A-31), member A is 159 m thick. The upper two-thirds of member A consist of upward-thickening and -coarsening amalgamated sandstone beds. Fine-grained deposits form less than 50% of the upper interval. The top of the member is placed at an abrupt change from amalgamated sandstone beds containing a shallow-marine invertebrate fauna to upward-fining channelized sandstone beds characteristic of member B.

At the type section the lower 60 m of member A consists dominantly of fine-grained deposits. A basal green-gray, structureless mudstone 18 to 27 m thick contains abundant large linguloid brachiopods. This is overlain by black phyllitic shale which grades upward to argillaceous siltstone and very fine-grained sandstone. Sandstone interbeds in the succession also coarsen and thicken upsection. The fine- to medium-grained sandstone beds range from 0.5 to 1 cm thick low in the interval, to 8 to 12 cm thick near the top. Sandstone beds have sharp bases, are generally graded, and either lack internal structures or have low-angle cross-stratification. Sandstone beds compose less than 20% of the lower part of member A.

Amalgamated sandstone beds compose more than 50% of the upper 100 m of the member. These amalgamated intervals, up to 6 m thick, are interbedded with gray to black structureless sandy siltstone and mudstone. Individual sandstone beds 5 to 15 cm thick are graded and lenticular. The sandstone is composed of a mixture of fine- to medium-grained, subangular to subrounded grains of chert, argillaceous chert, and vein quartz with variable amounts of shallow-marine invertebrate skeletal material. Scattered beds of pebbly sandstone contain subangular to subrounded chert pebbles less than 1 cm in diameter, with rare pebbles up to 3 cm in diameter. Sandstone beds typically have irregular, sharp bases with a relatively coarse-grained basal deposit composed of shells of a mixed fauna of marine invertebrates and/or shale rip-up clasts (fig. 7.2.a). Beds are graded and either internally structureless or the basal deposits are overlain by low-angle cross-stratification and ripples. Locally, mud drapes cap ripple cross-laminae.

Significant lateral variation occurs at the top of member A. At a locality 8 km southwest of the type section, the lower 60 m is similar to the type section. However, the upper 30 m includes a 12 m thick sandstone interval overlain by maroon mudstone (see Appendix H, measured section 88A-1). The sandstone interval has a sharp base and contains beds 2 to 4 cm thick of well-sorted sandstone having indistinct low-angle cross-stratification. An interval 20 cm thick of ripple cross-laminated sandstone beds 1 to 2 cm thick marks the top of the sandstone interval. Molds of several different species of large-ribbed bivalves are preserved on the upper surface of this bed. Gray muddy siltstone abruptly overlies the sandstone and grades upward to a maroon mudstone. Scattered, structureless beds 1 to 10 cm thick of fine-grained sandstone and fossiliferous limestone

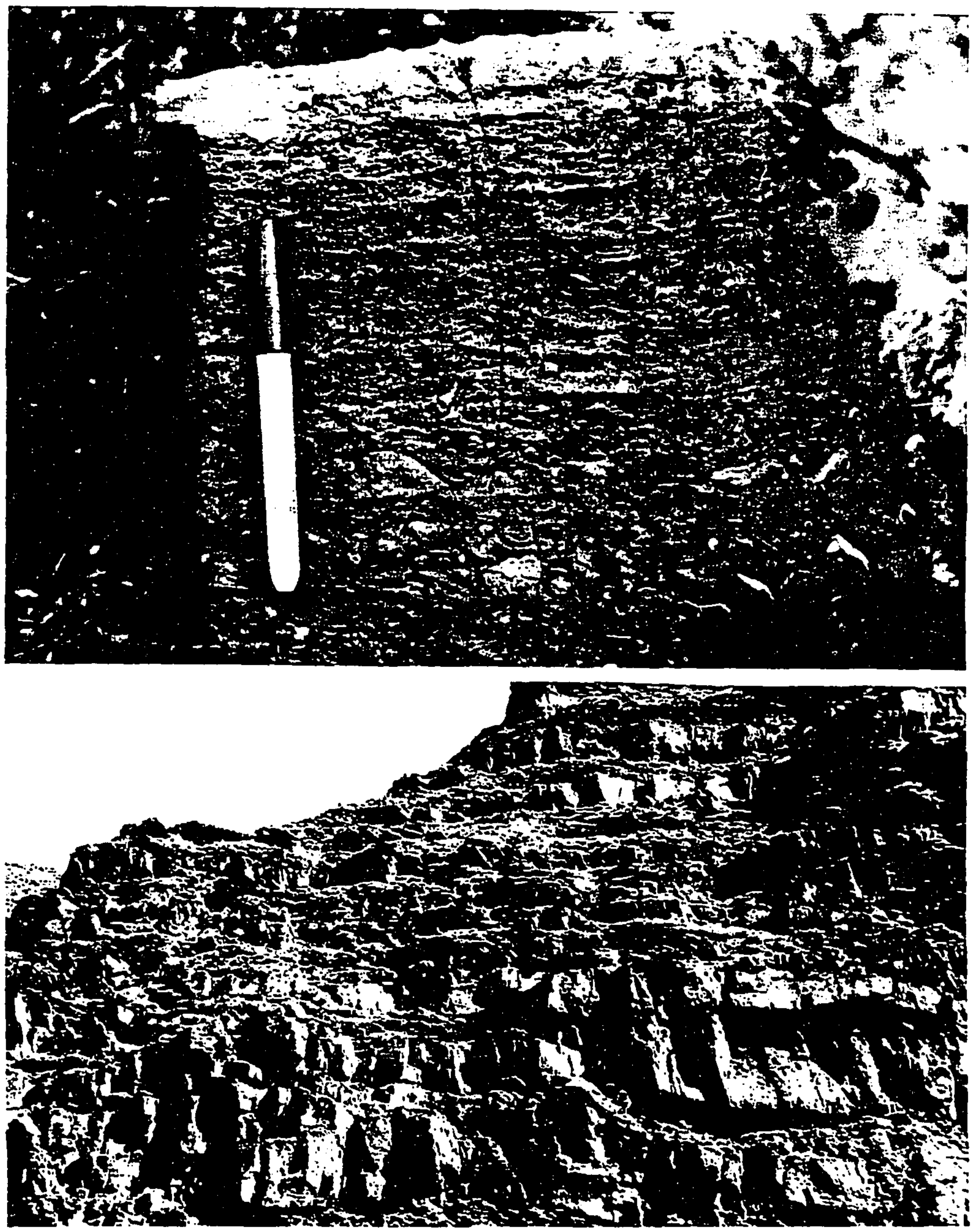


Figure 7.2. (A) Sandstone bed, member A, Ulungarat formation. Storm-concentrated shell deposit at the base is overlain by bioturbated sands with some preservation of symmetrical ripple cross-lamination. Pen for scale (14 cm). (B) Upper part of member B, Ulungarat formation. Upward-fining channel-fill deposits each overlain by ripple cross-laminated sandstone and horizontally laminated mudstone. Channelized beds are 1 to 3 m thick.

are interbedded in the mudstone. The interbedded, bioturbated maroon mudstone, sandstone, and limestone contain a more diverse faunal assemblage than is found lower in member A.

7.A.1.b. Fossils recovered from member A

The green-gray mudstone at the base of the formation contains abundant large inarticulate brachiopods identified as *Bicarinatina* n. sp. of Eifelian (early Middle Devonian) age (L.Y. Popov, All-Union Geological Research Institute (VSEGEI), Russia, written communication, 1991; Popov et al., in review). In addition, the basal 18 to 27 m thick basal mudstone contains *Ladjia* sp. (an ambocoelid brachiopod), as well as fragments of nuculoid bivalves, nautiloid cephalopods, and ramose bryozoans (R.B. Blodgett, U.S. Geological Survey, written communication, 1992). Interbedded sandstone deposits higher in member B contain a murchisonid gastropod (new genus) and a *Coelotrochium* sp. (a dasycladacean alga) also dated as Eifelian (R. B. Blodgett, written communication, 1991). Additional invertebrate fauna recovered include several indeterminate species of bivalves (including nuculoid bivalves) and several species of brachiopods (including reticularid brachiopods). Species identified include *Spinatrypa* sp. and *Naticopsis* (*Jedria*) sp. cf. N. (J.) *costatus* D'Archiac and DeVerneuil (R.B. Blodgett, written communication, 1992). One sample contained fish plates.

Fauna recovered from the uppermost beds of member A include crinoids, dendroid tabulate corals, reticularid brachiopods, dechenellid trilobites, bellerophontid and straparollid gastropods, several species of bivalves (including pectenoid and nuculoid bivalves), and stick-like bryozoan (R. B. Blodgett, written communication, 1992).

7.A.1.c. Depositional environment of member A

Member A records deposition within an upward-shallowing marine setting. Stratigraphic position below nonmarine fluvial deposits (described below) support an interpretation of a deltaic setting. The record begins with deposition of mudstone in the upper prodelta to subaqueous delta plain. The pattern of upward-coarsening, structureless mudstone to siltstone is characteristic of increasing proximity to the source of suspended terrigenous sediment. Interbedded graded sandstone beds with sharp bases, shale rip-up clasts, fossil hash, low-angle cross-stratification, and ripple cross-lamination were deposited by waning-flow, high-energy traction currents. The presence of marine fossils in lag deposits indicates reworking of marine sediments. Mud drapes, trace fossils, and bioturbation on upper sandstone bedding surfaces indicate intervals of slow deposition of suspended sediment. Alternating deposition from suspension and higher-energy traction currents indicates episodic flows of waning strength. Such episodic deposition is characteristic of storm-dominated coasts (Walker, 1985). Upward-thickening and -coarsening of these sandstone beds records increasingly proximal deposition, with an upward transition from fine-grained mud into sandstone-dominated deposits. This pattern of sedimentation is consistent with an upper prodelta to subaqueous delta-plain succession.

The interval present at the top of member A at the southwestern locality is not present at the type locality. Well-sorted sandstone beds with low-angle cross-stratification and large-ribbed bivalves indicate a high-energy environment. The overlying fine-grained sediments with a shallow-marine faunal assemblage suggest a low-energy setting with deposition from suspension under generally quiet conditions. Thin bioturbated sandstone beds interbedded in the mudstone may be storm-washover or crevasse-splay deposits. The proximity of these contrasting deposits suggests a very shallow, protected environment behind a barrier, perhaps a bay-mouth bar and interdistributary bay in a delta-plain setting. Similar settings were described by Elliott (1974 and 1986) and Reineck and Singh (1980). The sharp upper contact at the top of member A, with only locally preserved interpreted distributary-bay deposits, suggests erosion and reworking of the delta-plain succession by progradation of the overlying fluvial system.

7.A.2. Member B

7.A.2.a. Description of member B

Member B is composed of chert granule to pebble conglomerate, chert arenite, and siltstone in channelized fining-upward intervals in an overall coarsening-upward succession that is 129 m thick at the type section. The lower half of this succession is dominated by a red mudstone with less than 40% of the succession consisting of channelized deposits. The upper half has less mudstone and consists of 70 - 80% channel-fill deposits (fig. 7.2.B). The base of the member is placed at the base of the lowest thick, conglomeratic, channelized, fining-upward interval. This contact is coincident with the disappearance of marine fossils and marks an abrupt change in the character and organization of the deposits.

Each upward-fining interval is 1 to 3 m thick and has a concave-upward base that truncates underlying deposits. Coarse-grained, locally conglomeratic, sandstone beds organized as trough and tabular sets of planar cross-stratified deposits fill the basal scours. Sandstone beds at the top of each interval are ripple cross-laminated and are interbedded with and overlain by horizontally laminated siltstone.

Rose-red mudstone with green-gray mottling overlies and laterally interfingers with each of the pebbly sandstone and sandstone intervals. Mudcracks and root casts are visible in the mudstone. Deposits are laterally extensive across outcrop exposures. Interbedded with the red mudstone are intervals 3 to 8 m thick of stacked, medium- to fine-grained sandstone beds. Individual beds are 2 to 18 cm thick. Characteristically, these beds have erosional bases, usually fine upward, and are ripple cross-laminated at their tops. Locally, trough cross-stratified sandstone beds 5 to 10 cm thick by 30 to 50 cm wide are overlain by ripple-laminated sandstone.

7.A.2.b. Depositional environment of member B

Upward-fining intervals of channelized sandstone represent channel and point-bar deposits whereas intervening rose-red mudstones represent flood-plain deposits, indicating deposition by meandering fluvial system(s). Similar deposits were described by Collinson (1986). The sharp lower contact places nonmarine fluvial deposits over deposits of the marine subaqueous delta-plain and locally preserved inferred interdistributary-bay deposits. Deposits of member B record progradation of a coarse-grained fluvial system over the delta.

Based on fine grain-size, mud cracks, root casts, lateral continuity, and color, the mudstones of member B are interpreted to be flood plain deposits. The red color, root casts, and mudcracks indicate subaerial exposure of interchannel areas with deposition occurring during overbank flooding events. The rose-red color of the mudstone is probably syngenetic or diagenetic because there are no red sediments in the probable source area. Syngenetic red beds suggest subaerial exposure in a warm climate with alternating wet and dry conditions. Clark (1962) attributed syngenetic red beds to reflect either alternating rainy and dry seasons and/or successive flooding and drying of the flood plains. Such rose-red and greenish-gray mottling is diagnostic of paleosols (Atkinson, 1986). Retallack (1988) attributed similar mottling to reduction halos around roots. In modern environments, similar mottling is produced by fluctuating water levels and movement of iron around cracks, burrows, and roots (Atkinson, 1986, citing Fitzpatrick, 1980). The interbedded graded sandstone beds were each deposited by a single flood event with ripple cross-lamination at the top of the beds indicating waning flow deposition. Intervening mudstone beds were deposited from suspension during flooding. Interbedding of these sandstone beds in mudstones suggests sheet flood, levee, and crevasse-splay overbank deposits.

The progressive infilling of erosional channel scours by processes of lateral accretion is typical of point-bar deposits, where the fining-upward character of each interval indicates waning-flow conditions in response to progressive decrease in water depth (Allen, 1963). The upward-fining channelized sandstone intervals are interpreted to be the record of migration of meandering fluvial channels. Within member B, progradation of the fluvial system is indicated by the upward-coarsening of the channel-fill deposits, and by the vertical change from dominance of flood-plain deposits to dominance of coarse-grained channel-fill deposits. The upward change from flood-plain dominated deposition to dominance of fluvial channels records an upward increase in stream gradients.

7.A.3. Member C

7.A.3.a. Description of member C

In member C, thick, multistory, amalgamated channelized conglomerate and conglomeratic sandstone deposits fill major erosional scours incised into finer-grained deposits (fig. 7.3). Brown-red mudstone and interbedded thin sandstone beds underlie, are lateral to, and overlie the cliff-forming conglomerates. At the type section of the Ulungarat formation, member C is 85 m thick. The base of member C is placed at the base of the lowest, thick, multistory conglomerate succession that marks a fundamental change in the organization of the conglomerate and sandstone deposits. The top of the member is placed at the top of the stratigraphically highest multistory channelized conglomerate succession.

The thick successions of conglomerate and sandstone are confined within major erosional topographic lows dissected into the underlying mudstone and thin sandstone beds. At the largest scale, this erosional topography is a concave-up surface 50 to 75 m wide and 20 to 30 m deep, and is marked by erosional scours. The fill is composed of clast-supported chert pebble to cobble conglomerate beds 1 to 3 m thick. These are erosional into underlying beds and onlap the underlying confining major erosional surface. Shale rip-up clasts are present at the base of some beds. The conglomerate beds are massive to horizontally stratified, in places are faintly trough cross-stratified, and crudely fine upward. Pebbly sandstone beds 8 to 15 cm thick are trough cross-stratified. The upper surfaces of the major multistory channel complexes are flat and overlain by the same type of deposits that underlie the major erosional scour.

Brown-red mudstone and thin, fining-upward sandstone cycles underlie, are lateral to, and overlie the cliff-forming conglomerates. Fining-upward cycles of coarse-

Figure 7.3. Amalgamated braided channel succession, member C of Ulungarat formation. Entrenched multistory, conglomeratic braided-channel system fills large-scale erosional topography. Local relief is 100 m. Geologist for scale. Upper part of measured section 90A-31, Appendix H.

to fine-grained sandstone, 10 to 60 cm thick, extend laterally across outcrop exposures. Horizontally and ripple cross-laminated fine-grained sandstone beds are present at the tops of the cycles. The sandstone beds are erosional into and overlain by intervals of brown-red mudstone with green-gray mottling, similar to that observed in member B.

7.A.3.b. Depositional environment of member C

The alternation of incised channel-fill deposits and laterally equivalent unconfined flow deposits characterizes member C. Laterally, beyond the confined deposition of the entrenched channel successions, thin, upward-fining sandstone beds with basal concave-upward erosional scours record deposition in minor channels. The lateral continuity of these thin sandstone beds suggests less confined bedload transport, whereas interbedded mudstones record deposition from suspension during the waning phase of flood events. The truncation of the finer-grained strata by major erosional surfaces beneath the entrenched channel systems indicates that a drop in base level caused dissection. Within the entrenched channel systems, the coarse grain size and general lack of fine-grained cohesive sediments is a characteristic of coarse-grained, braided fluvial systems (Rust and Koster, 1984). Multistory, crudely horizontal- and cross-stratified coarse-grained conglomerate beds suggest deposition in low-sinuosity channels, whereas coarse grain size, abrupt changes in grain-size, and poor sorting are consistent with deposition during high-energy flood events (Rust, 1972; Miall, 1977 and 1978; Rust 1978). Within the channel-fill successions, trough cross-stratified pebbly sandstone beds record migration of sinuous crested dunes.

7.A.4. Member D

7.A.4.a. Description of member D

Member D is a succession of mottled, red mudstone with sparse, laterally discontinuous sandstone lenses. The member is approximately 80% mudstone. This member is 21 m thick at the type section, but is approximately twice as thick in the valley to the east. The base of member D is placed at the top of the uppermost interval of thick channelized conglomerate beds. The top is placed at the lowest appearance of oncolitic black algal limestone or calcareous black mudstone and siltstone characteristic of the Mangaqtaaq formation.

Sandstone lenses are generally 8 to 10 m across and 2 to 3 m thick, have concave-upward bases, and fine upward from coarse- to fine-grained chert arenite. Some intervals contain black, gray, and white chert pebbles at the base and fine upward to coarse-grained sandstone.

7.A.4.b. Depositional environment of member D

The mottled rose-red and green-gray mudstone is similar to the mottled mudstone in member B and is interpreted to be flood plain deposits. The infilling of erosional channel scours by upward-fining intervals reflects waning-flow deposition. Channelized sandstone deposits interbedded with extensive flood-plain deposits are typical of sand-rich fluvial systems (Collinson, 1986). The sandstone beds are interpreted to record channel migration over the flood plain. Significant reduction in sand dispersal and deposition compared with member C is indicated by the dominance of flood-plain deposits and suggests a decreased supply of coarse-grained sediment from the source terrain.

7.B. LATERAL VARIATION OF THE ULUNGARAT FORMATION

The Ulungarat formation is thickest in the area of the type section in the Aichilik pass thrust sheet. To the southwest within the same thrust sheet, the marine deposits of member A are thinner and, at the top, include an interval not present at the type section (fig. 7.4; Appendix H, measured section 88A-1). At this location, the fine-grained dominated lower 30 m of member A has the same lithologies and organization as at the type locality, but the overlying interval of alternating sandstone and mudstone is much thinner and interpreted to be interdistributary bay deposits. This interval is described in section 7.A.1. Immediately east of this locality, the marine succession appears to be thicker and to lack this upper interval. A steep slope covered with loose fine-grained talus cover this transition. This over-all thinner, less sandy succession, with preserved fine-grained deposits at the top may reflect deposition in a less active part of the delta at some distance from the overlying active fluvial channels of member B. The fluvial channels may have eroded much of the sub-aerial delta plain succession.

Farther south in the Kongakut River thrust sheet, the Ulungarat formation has the same coarsening- and thickening-upward organization as in the area of the type section, but the succession is depositionally thinner and finer-grained (fig. 7.4; Appendix H, measured sections 90A-93 and 90A-112). At the base of succession, member A is less than 90 m thick. A coarsening and thickening-upward interval of fining-upward fluvial cycles overlies member A and is 150 to 190 m thick. Thick, multistory, conglomerate deposits are absent and there is no evidence of an entrenched channel system such is characteristic of member C. The succession is abruptly overlain by the Kekiktuk conglomerate.

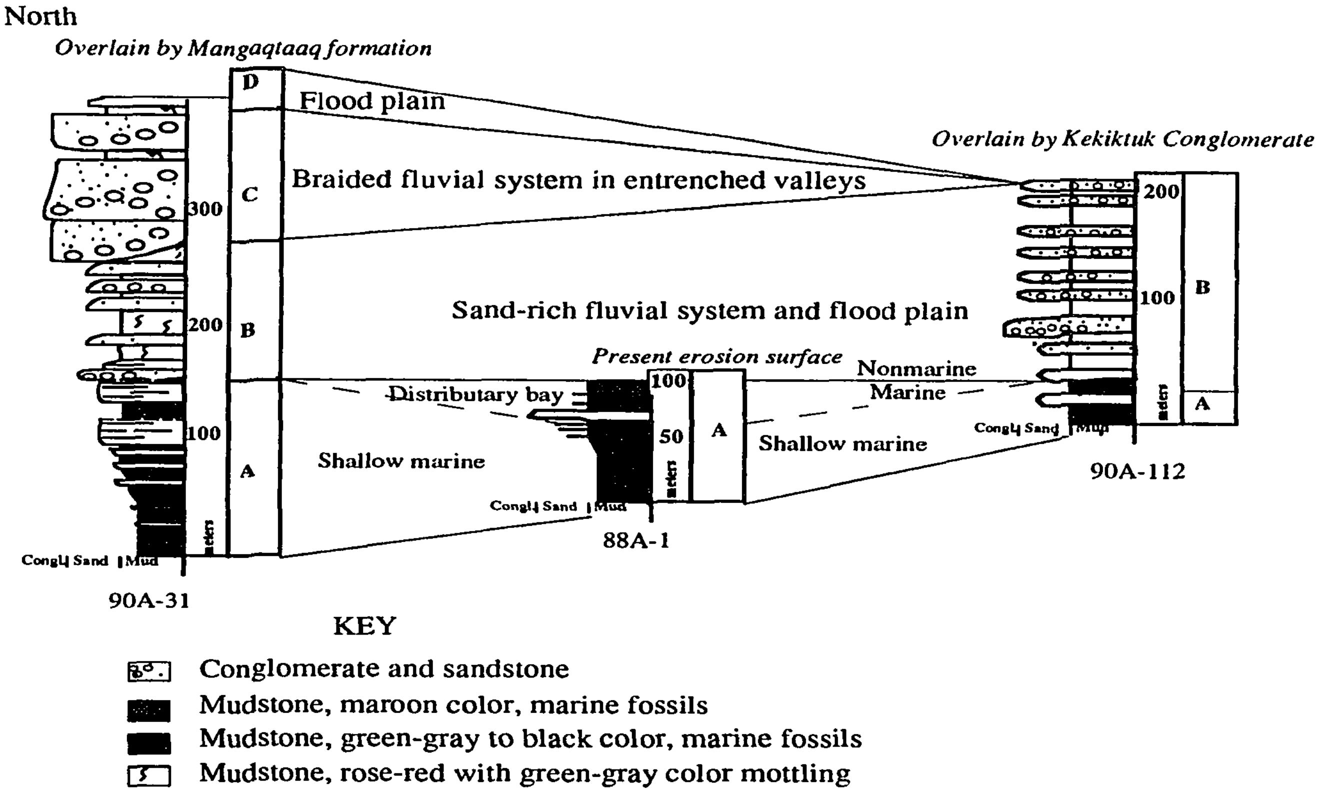


Figure 7.4. Generalized stratigraphic colunms showing lateral variability of the Ulungarat formation. Sections 90A-31 and 88A-1 are in the Aichilik pass thrust sheet. Section 90A-112 is in the Kongakut River thrust sheet. See Appendix H for detailed measured sections.

The thinner marine succession in the Kongakut River thrust sheet may be due to topography on the depositional surface or to truncation of the lower part of the unit during thrusting. The thinner nonmarine interval could be due to erosion prior to deposition of the Kekiktuk Conglomerate. Alternatively, the difference in thickness and organization may be due to lateral facies changes. The overall thinner, finer-grained nonmarine succession and the lack of entrenched upper fan deposits suggest these more southern exposures may record deposition at a greater distance from the source area. The coarsening and thickening upward succession indicating progradation of the alluvial system.

7.C. AGE OF THE ULUNGARAT FORMATION

Invertebrate fossils recovered from the marine member (A) are of Eifelian (early Middle Devonian) age. The green-gray mudstone at the base of the formation contains large inarticulate brachiopods identified as *Bicarinatina* n. sp. of Eifelian age (Popov et al., in review). Interbedded sandstone deposits contain murchisonid gastropods (new genus) and a *Coelotrochium* sp. (a dasycladacean alga) also dated as Eifelian (R. B. Blodgett, United Geological Survey, written communication, 1991).

The age of the nonmarine upper members is unknown, but is bracketed by the Eifelian age of the underlying shallow-marine deposits and by the age of unconformably overlying Kekiktuk Conglomerate, which in the area contains plant fossils assigned a tentative Early Mississippian age (R. Spicer, University of Oxford, oral communication, 1989). Based on these relationships, the age of the nonmarine upper members may range into the Late Devonian.

7.D. EVOLUTION OF ULUNGARAT DEPOSTIONAL SYSTEMS

The Ulungarat formation is interpreted to record the progradation of an alluvial fan over a delta (fig. 7.5). At the base of the formation, the shallow-marine succession (member A) records progradation of an upper prodelta to subaqueous delta-plain transition. The sharp upper contact over subaqueous delta plain and locally preserved inferred interdistributary-bay deposits suggests reworking of much of the upper delta plain deposits by the overlying fluvial system. In addition, erosion may have been in response to a local drop in base level.

Deposits of the nonmarine members of the Ulungarat formation are interpreted to be the record of prograding, fluvial-dominated, alluvial fan(s). The coarsening- and thickening-upward nonmarine succession, angular to poorly rounded clasts, deposition close to the source area by high-energy streams, and oxidized finer-grained marginal deposits support this interpretation. The upward increase in stream gradients is consistent with alluvial fan deposition. Low-gradient streams are to be expected on a lower fan, whereas increasing stream gradients characterize an upper fan (Collinson, 1986; Rust and Koster, 1984). The alternation of entrenched channel systems containing proximal braided fluvial deposits with laterally equivalent unconfined flow deposits is typical of upper alluvial fans (DeCelles et al., 1991) and may be intrinsic to the depositional setting. An upward transition into upper alluvial-fan deposits is the distinctive characteristic that distinguishes a fluvial-dominated alluvial fan from a braid-plain succession (Nemic and Steel, 1988).

Incision and deposition of coarse-grained fluvial deposits is characteristic of an upper, fluvial-dominated alluvial fan (Rust and Koster, 1984), which builds by a three-part cycle of dispersion, entrenchment, and eventual backfilling (DeCelles et al., 1991,

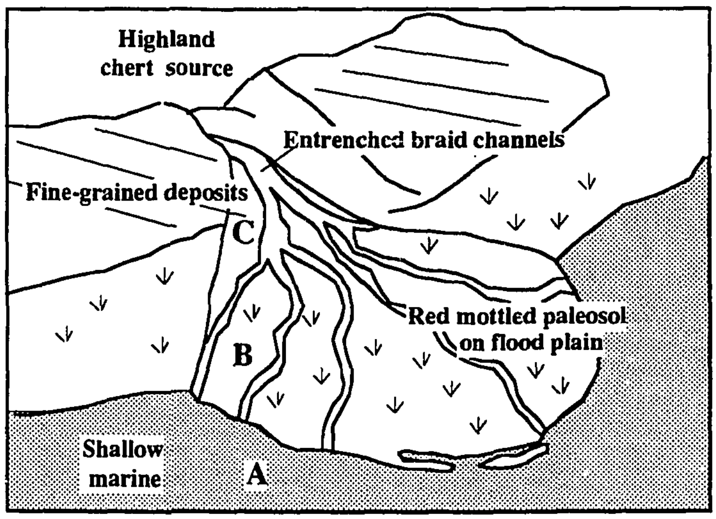


Figure 7.5. Schematic diagram illustrating depositional system of Ulungarat formation. A is member A, shallow marine; B is member B, lower- to mid-alluvial fan; C is member C, upper alluvial fan with entrenched distributary channel system; member D not shown.

with reference to Schumm et al., 1987). Dispersion of fine-grained deposits on the upper fan results in building the upper fan above local base level, causing channel entrenchment in order to reestablish gradient to local base level. Once the channel is backfilled, dispersed deposition is reestablished across the upper surface of the fan (DeCelles et al., 1991). Amalgamated braid-channel deposits of member C are interpreted to be the deposits of an entrenched channel system whereas the fine-grained deposits record dispersion on the upper fan. The thinner and finer-grained succession on the Kongakut River thrust sheet suggest deposition in a more distal delta to mid-alluvial fan setting.

Although some authors believe that debris flow deposits are necessary components of alluvial-fan successions, McGowen and Groat (1971) and Nemic and Steel (1988) have shown that the absence of such deposits does not preclude a fan interpretation. The absence of vegetation in a source area, coupled with an active fluvial system, will promote the movement of detritus by stream flow rather than debris flow. Devonian interfluvial areas lacked vegetation because land plants had only colonized lowland areas (Schumm, 1968). Therefore, fluvial processes could dominate deposition on a fan. During Ulungarat deposition, debris flow deposits could have been limited to a small area at the fan head adjacent to the greatest topographic relief and therefore not exposed in the study area.

The Ulungarat formation is thought to have been deposited in a topographically immature setting with considerable relief. The coarse-grained deposits and progradational character of the depositional system suggest drop in base level and/or uplift of source area with active faulting and/or a change in climate. The Middle to Late Devonian was a time of eustatic sea level rise (Johnson et al., 1985), so an eustatic sea level fall is an unlikely explanation for progradation. Based on lithologic similarity and proximity, the Romanzof chert is the most likely source terrain for the alluvial fan deposits. These relationships suggest that the cherts formed a highland adjacent to the southward-prograding alluvial fan(s). The fine-grained character of member D, at the top of the formation, reflects a diminished supply of coarse-grained sediment in response to a decrease in relief between the source area and the depositional basin. This change may be due to erosion and deposition, cessation of tectonic uplift and stabilization of areas, or to a change in the sites of tectonic uplift and subsidence.

8. MANGAQTAAQ FORMATION

The Mangaqtaaq formation (informal name) is a succession 200 m thick of black algal limestone, sandstone, and interbedded mudstone that can be traced along strike for only 10 km (fig. 8.1). This localized unit is present in the Aichilik pass and Kongakut River thrust sheets of the continental divide succession. The type section is in a small west-flowing tributary of the upper Kongakut River on the south side of Mangaqtaaq Ridge (new name) in the west half of Section 9, T. 5 S., R. 38 E., Demarcation Point (A-4) quadrangle (69° 1.4' N, 143° 6.4' W) (Locality C, Plate 1; Appendix H, measured section 90A-27). Mangaqtaaq is an Inupiat Eskimo word meaning "black color" (J. Nageak, University of Alaska Fairbanks, personal communication, 1989), which describes these rocks. A native Alaskan name is appropriate because this area is within the traditional hunting ground of the Inupiat Eskimo. This is a distinctive, mappable unit within the Devonian to Mississippian succession and it has not been previously described . The Mangaqtaaq formation overlies the Ulungarat formation where that unit is at its maximum preserved thickness within the study area.

Most of the formation is best exposed at the type section, but the basal contact is not exposed and an apparent 75 to 100 m of section at the base of the unit is covered by vegetation. Better exposures of the basal contact are present at location B (Plate 1) 1.5 km west of the type section and above location A (Plate 1) 2.5 km farther west. At these locations, the succession overlies the Middle to Upper(?) Devonian Ulungarat formation along a sharp contact interpreted to be an unconformity. Above location A (Plate 1), gently southeast-dipping sandstone beds both above and below the Ulungarat -

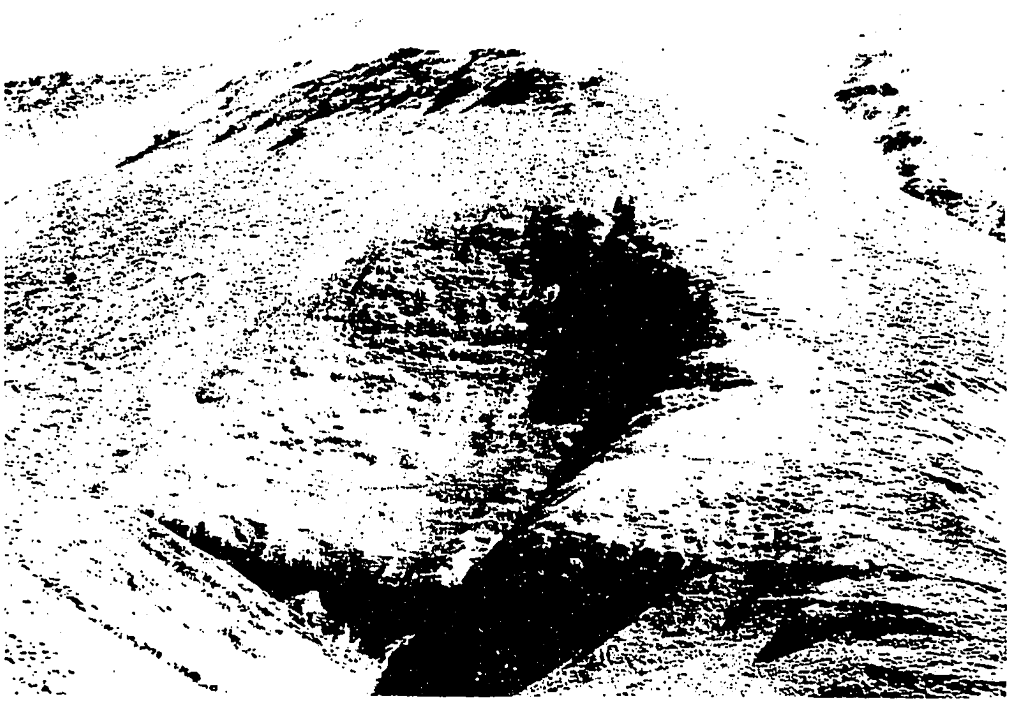


Figure 8.1. Overview of the Mangaqtaaq formation at the type section. Lower resistant interval is 40 m thick. See measured section 91A-27, Appendix H for detailed description.

Mangaqtaaq contact are discordant with the contact surface, which dips slightly more steeply to the southeast (fig.8.2). The Mangaqtaaq formation appears to onlap the upper surface of the Ulungarat formation. The contact itself is covered, but could be an originally sloping erosional surface or a Devonian or Mississippian low-angle normal fault. The younger-over-older relationship across the contact argues against this being a Cretaceous(?) to Tertiary thrust fault. At location B, this contact is marked by an abrupt upward change from rose-red and green-gray mottled mudstones of the upper Ulungarat formation to calcareous black mudstone. Locally the underlying mudstone of the Ulungarat formation is an atypical yellow-tan color.

Two probable high-angle faults locally offset the contact between the Ulungarat and Mangaqtaaq formations (Plate 1). At the eastern locality, a high-angle offset is down-to-the-east an estimated 20 m. The relatively down dropped side is filled with meter-sized blocks of mudstone in a mudstone matrix. The blocks are oriented at various angles, suggesting a large debris flow, colluvium, or tectonic breccia. Above location A (Plate 1) 2.5 km to the west, the upper Ulungarat surface is offset 10 to 15 m down-to-the-west juxtaposing black calcareous mudstone of the Mangaqtaaq formation against Ulungarat formation. It is not possible to determine if this offset continues upward into the uniform black mudstone, but there is no offset of the overlying Kekiktuk Conglomerate. These high-angle faults appear to be pre- to syn-Mangaqtaaq faults and indicate active faulting prior to or during Mangaqtaaq deposition.

The upper contact of the Mangaqtaaq formation is interpreted to be a low-angle unconformity beneath the Kekiktuk Conglomerate. A good exposure of the contact has not been closely examined but, locally, an angular discordance, with underlying beds

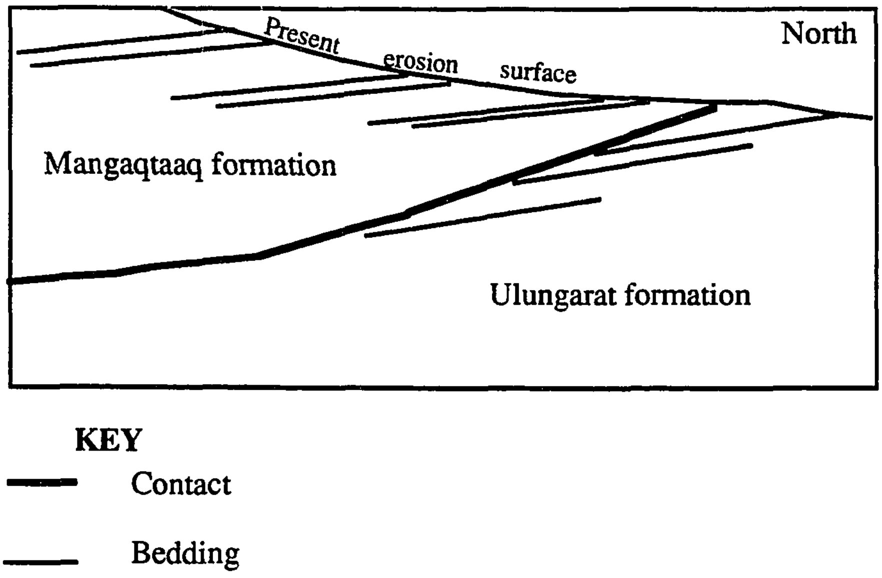


Figure 8.2. Schematic diagram of bedding relationships across the contact between the Ulungarat and Mangaqtaaq formations above locality A, Plate 1. These relationships are discussed in section 8.1.

dipping up to 10° more steeply to the south, can be observed between Mangaqtaaq beds and the overlying Kekiktuk Conglomerate. This discordance can also be seen in the map pattern (Plate 1), which shows the lateral truncation of the Mangaqtaaq formation beneath the Kekiktuk Conglomerate. The younger-over-older relationship across the contact and the contact cutting down stratigraphic section in the direction of tectonic transport argue against this contact being a thrust fault.

The Mangaqtaaq formation is best exposed in the Aichilik pass thrust sheet. Both stratigraphic sections illustrated in figure 8.3 and the measured sections in Appendix H are in that thrust sheet. To the southwest, in the Kongakut River thrust sheet, the thickness and organization of the Mangaqtaaq formation are difficult to determine due to complex structures.

The formation includes four lithofacies: algal limestone, sandstone, pebbly sandstone, and black mudstone. The lower 80 to 100 m of the Mangaqtaaq formation consists of cyclic alternations 3 to 10 m thick of 1) intervals of interbedded algal limestone and sandstone with 2) thin intervals of recessive-weathering black mudstone (fig. 8.3 and 8.4). Contacts between these lithologies are typically sharp. The upper 90 m of the formation at the type section is rhythmically interlaminated black mudstone and siltstone. To the west, terrigenous conglomerate and coarse sandstone deposits are locally present within this thick upper black mudstone and siltstone interval (fig. 8.5, Plate 1, near locality B in unit MDms). Farther west, the unit entirely consists of black mudstone, is 140 to 160 m thick, and contains uncommon thin algal limestone and sandstone beds less than 3 m thick. In this area, the black mudstone lithofacies directly overlies the Ulungarat formation without an intervening limestone interval.

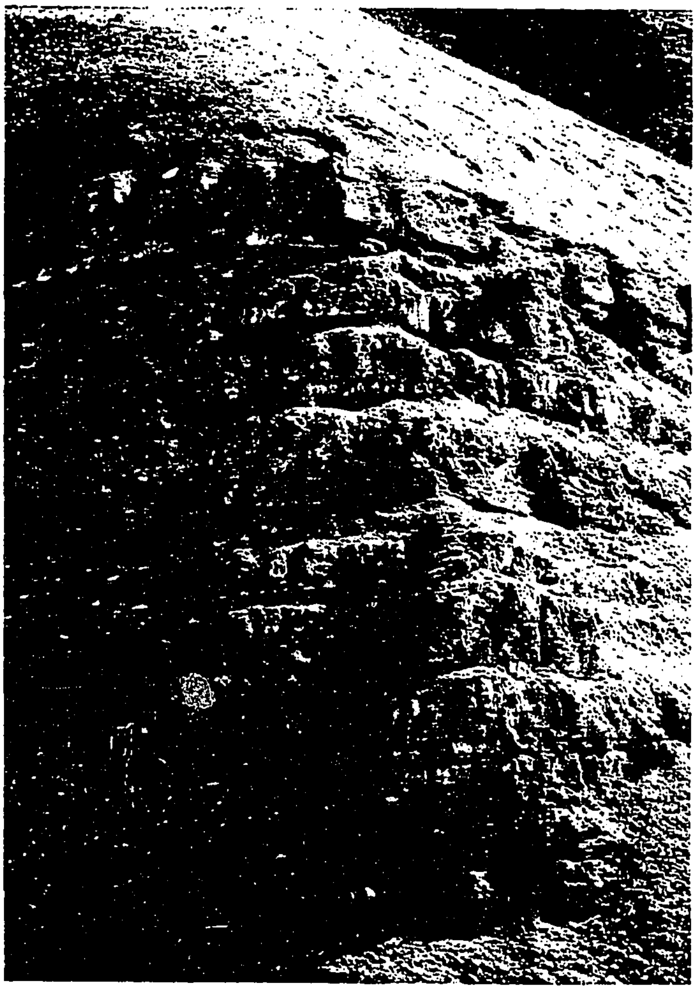


Figure 8.3. Outcrop character of the lower half of the Mangaqtaaq formation. Light-colored resistant units are interbedded algal limestone and sandstone lithofacies. Black recessive-weathering intervals are black mudstone lithofacies. Outcrop is 40 m high. Detail from figure 8.1.

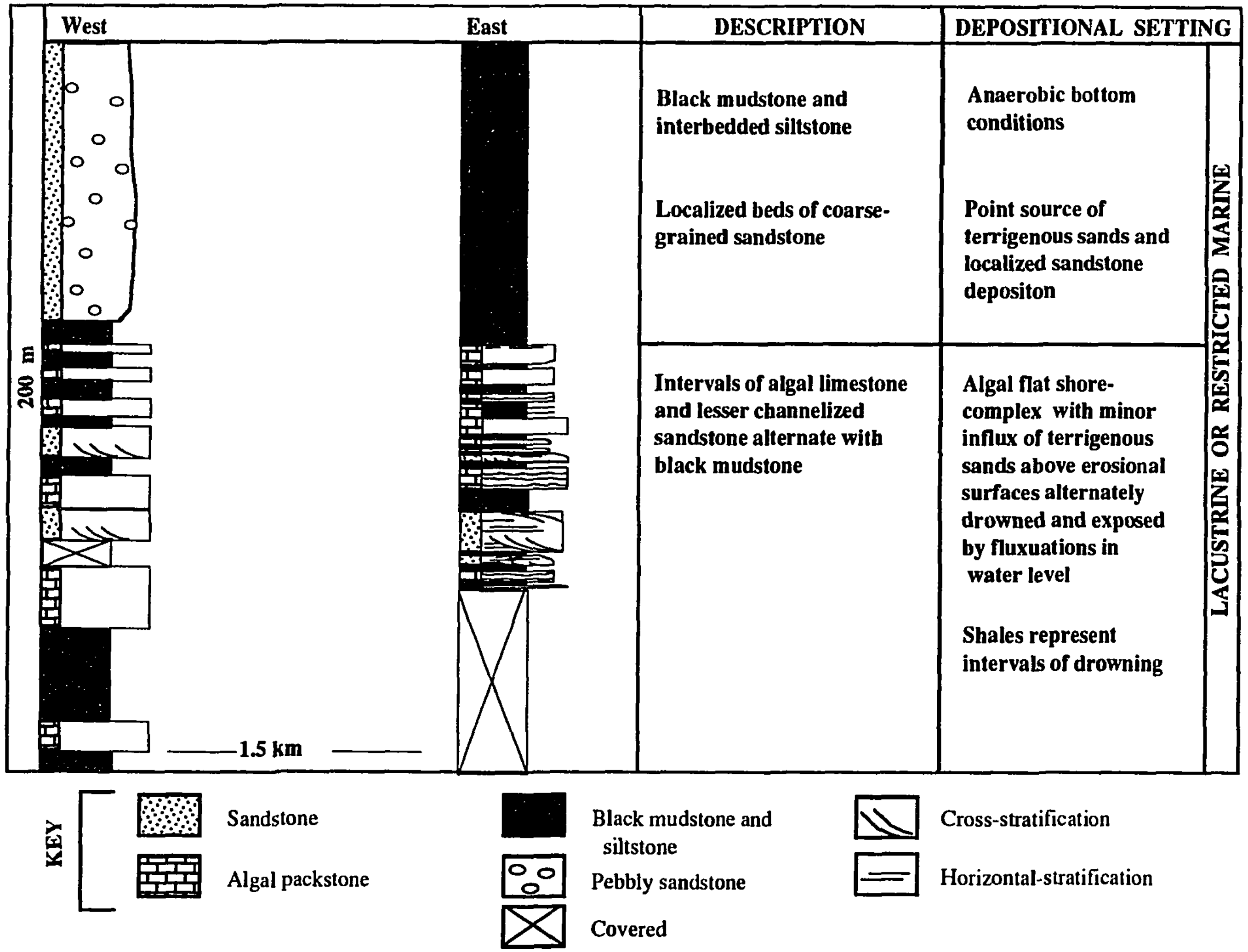


Figure 8.4. Generalized stratigraphic columns showing west to east change in the Mangaqtaaq formation. See Appendix H for detailed measured sections 91A-27 and 91A-31.

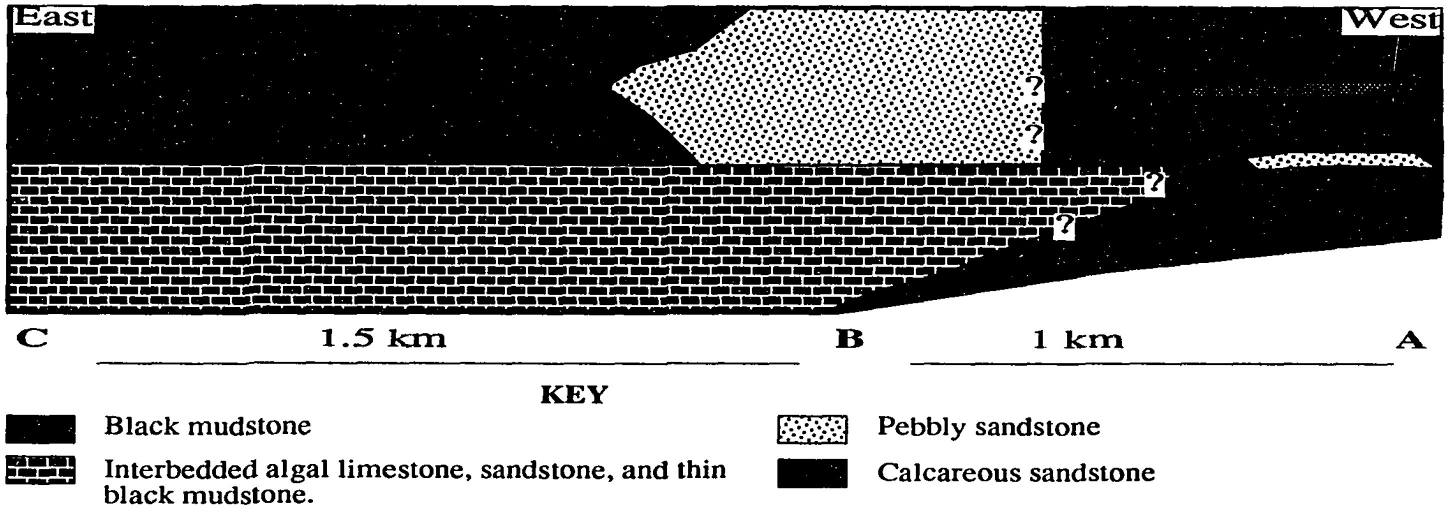


Figure 8.5. Schematic diagram of west to east lithofacies relationships in Mangaqtaaq formation. Lateral contact relationships between lithofacies are covered by scree slopes and therefore are unclear. A, B, and C correspond to locations on Plate 1.

8.A. DESCRIPTION OF LITHOFACIES

8A.1. Algal Limestone Lithofacies

8.A.1.a. Description of algal limestone

Thin-bedded (5 to 10 cm), black limestone is dominated by algal packstone to grainstone with lesser algal boundstone and contains calcareous algae, peloids, gastropods ostracods, serpulid-like worm tubes, black intraclasts, and micritic mud. The major component is calcareous algae, including the blue-green algae *Girvanella* (M. Mickey, Micropaleo Consultants, written communication, 1992) and *Ortonella* (?) (W. Nassichuk, Geological Survey of Canada, written communication, 1992), as well as several unidentified forms. The algae form a variety of laminated stromatolite structures and large oncoids. Locally, an interbed of black mudstone less than 1 cm thick overlies large domal algal structures and contains desiccation cracks. Laths of anhydrite are present in some algal structures. No conodonts were recovered, but one ichthyolith was found (Anita G. Harris, U.S. Geological Survey, written communications, 1988 - 91). No other fossils were recognized.

Large, irregular, spheroidal to ellipsoidal oncoids, commonly varying in size from 1 to 8 cm, are the most distinctive feature of the formation (fig. 8.6.a). Nuclei of the oncoids include shells, peloids, dense algal balls, and rare ooids. Most oncoids show an internal structure of concentric irregular layering of alternating porous and dense layers (fig. 8.6 b), although oncoids without growth rings are common. Growth rings in oncoids locally show partial truncation or marked changes in the direction of growth ring asymmetry.

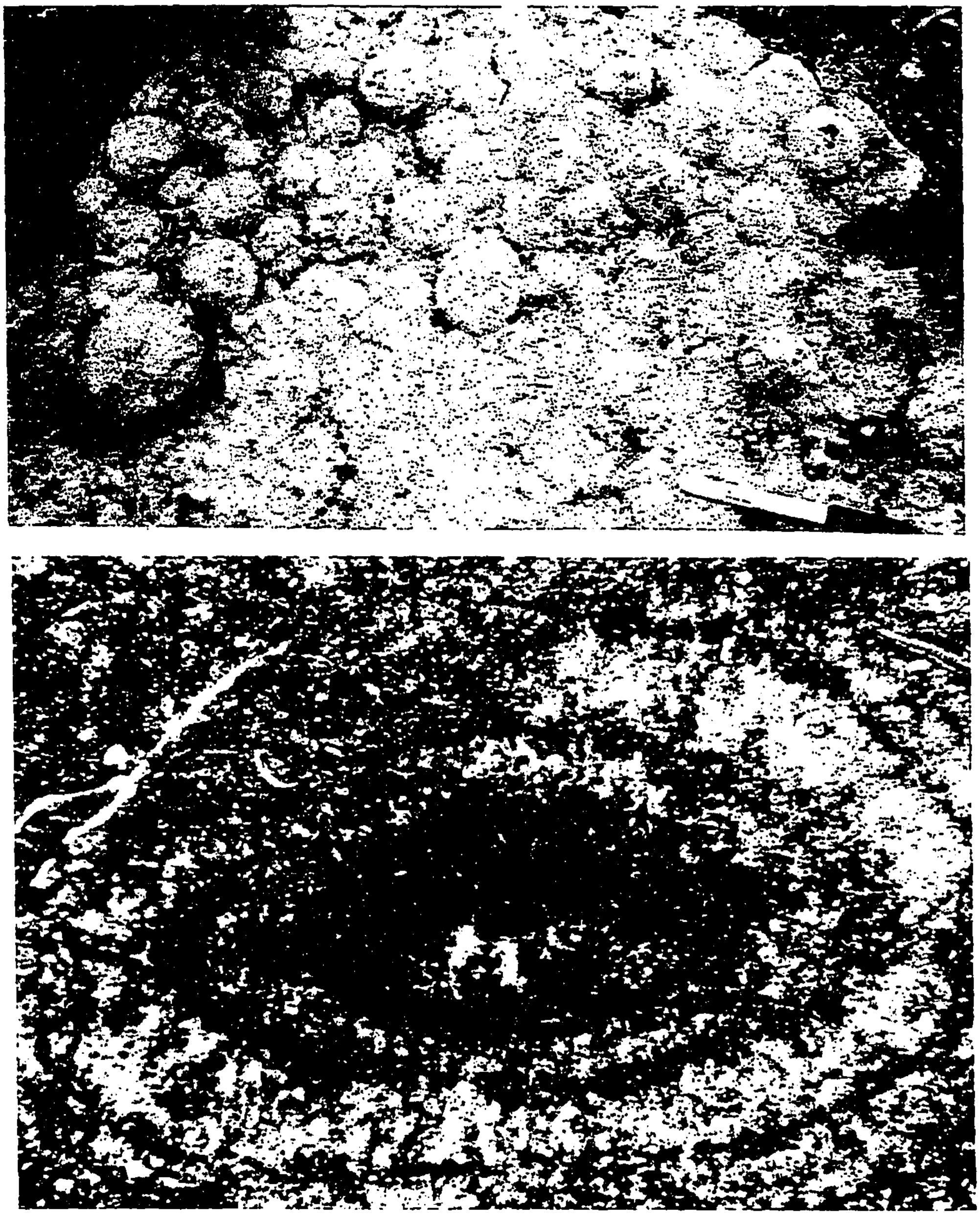


Figure 8.6. (A) Oncoids weathering from bedding surface, algal limestone lithofacies, Mangaqtaaq formation. Pen for scale. (B) Photomicrograph of internal structure of an oncoid. Oncoid is 1.85 mm in length.

Peloids are micritic, elongate to subrounded grains without recognizable structure, ranging from 1 to 2 mm in length. They are commonly associated with the algae. The shapes suggest that some are probably micritized bioclasts; others may be fecal pellets or fragments of clotted algae. Dark brown or black rims of indeterminate origin are visible on some grains.

Granule-size black intraclasts of mudstone to wackestone are common. Many contain ostracod and gastropod skeletal fragments. The grains are opaque, black, angular to subrounded, and sometimes thin and elongate.

8.A.1.b. Depositional interpretation

The algal limestone lithofacies records a shallow-water, high-stress environment probably having restricted circulation to account for the depauperate fauna. Stromatolites and oncoids require a warm environment within the photic zone and indicate shallow water (Wilson, 1975; Flugel, 1982). Mud cracks in black mudstone indicate local subaerial exposure (Allen and Collinson, 1986). *Girvanella* and *Ortonella* (?) are known to grow in both lacustrine and restricted, shallow-marine waters (Wray, 1977). The presence of anhydrite indicates a restricted basin and saline to hypersaline conditions at some time during deposition or later diagenesis. No definitive indicators of whether the basin was restricted marine or lacustrine were found.

The ellipsoidal shape and rough surface texture of the Mangaqtaaq oncoids are similar to those of modern lacustrine oncoids (Jones and Wilkinson, 1978; Smith and Mason, 1991). Internal truncation of growth rings indicates removal of part of the structure by abrasion, then reestablishment of algal growth. Differences in thickness of individual growth rings have been related to oncoid orientation, with the direction of maximum growth being upward toward maximum light (Jones and Wilkinson, 1978; Smith and Mason, 1991). Changes in sense of growth-ring asymmetry suggest overturning of oncoids, probably by infrequent storms. Studies of modern lacustrine oncoids have shown concentric banding or growth rings to form in response to annual seasonal changes, with growth occurring by *in situ* accretion of an entire concentric lamina, without the necessity of overturning (Jones and Wilkinson, 1978; Smith and Mason, 1991). This indicates that high-energy environments are not required for oncoid development. The large size, rough surface texture, and internal morphology of the Mangaqtaaq oncoids suggest an environment with fluctuating energy conditions. In summary, enough energy was periodically available to move the oncoids, causing abrasion and changing the sense of growth ring asymmetry, but movement was not frequent enough to smooth oncoid surfaces.

The black intraclasts, some of which contain invertebrate fossils, suggest erosion within the unit. Flugel (1982) described similar black intraclasts and attributed the black color to infiltration of organic substances into porous limestone beds or to bitumina formed in a reducing environment. Black intraclasts have been interpreted as evidence of subaerial exposure (Flugel, 1982). The black intraclasts are present in both the limestone and sandstone lithofacies, suggesting that major storms occasionally resulted in erosion of limestone substrates and deposition of this detritus along the entire shore complex and/or the intraclasts may have been reworked from subaerial exposed surfaces during lowstands.

In summary, the algal limestone lithofacies records a restricted, warm, shallow-water setting periodically disrupted by erosion, possibly during storm events. The limited fauna - blue-green algae, ostracods, gastropods - indicates deposition in a shallow-water, restricted, marine or lacustrine environment.

8.A.2. SANDSTONE LITHOFACIES

8.A.2.a. Description Of Sandstone Lithofacies

Rocks of the sandstone lithofacies contain a mixture of fine to medium, terrigenous and carbonate sand grains (fig. 8.7). The variable composition suggests derivation from several sources. Terrigenous sand and small pebbles are mixed with intraclasts of broken and abraded intrabasinal carbonate grains. The terrigenous sand consists of angular to subrounded chert and minor quartz. In addition to chert and quartz, terrigenous pebbles are composed of argillite clasts in chert cement, chert breccia in argillite, and chert breccia cemented with chert. Radiolarian ghosts are present in the chert clasts. The intrabasinal carbonate grains include ooids, broken oncoids and fragments of algal limestone, disarticulated ostracods, and gastropod shell fragments. Ooids have one to four laminae and occur only in the sandstone lithofacies. Purely oolitic grainstone has not been found.

The sandstone lithofacies occurs as discrete beds interbedded with algal limestone or black mudstone. Contacts with overlying and underlying units are sharp. Sandstone beds vary in thickness from a few centimeters to 100 cm. Thicker beds have erosional channelized bases, are trough cross-stratified, fine upward to ripple cross-laminated fine-grained sandstone, and are locally overlain by horizontally laminated black mudstone containing plant fragments.

The thinner (<20 cm) sandstone beds commonly have shallow-scoured bases and extend laterally along outcrop exposure for more than 10 to 20 m. The beds lack obvious

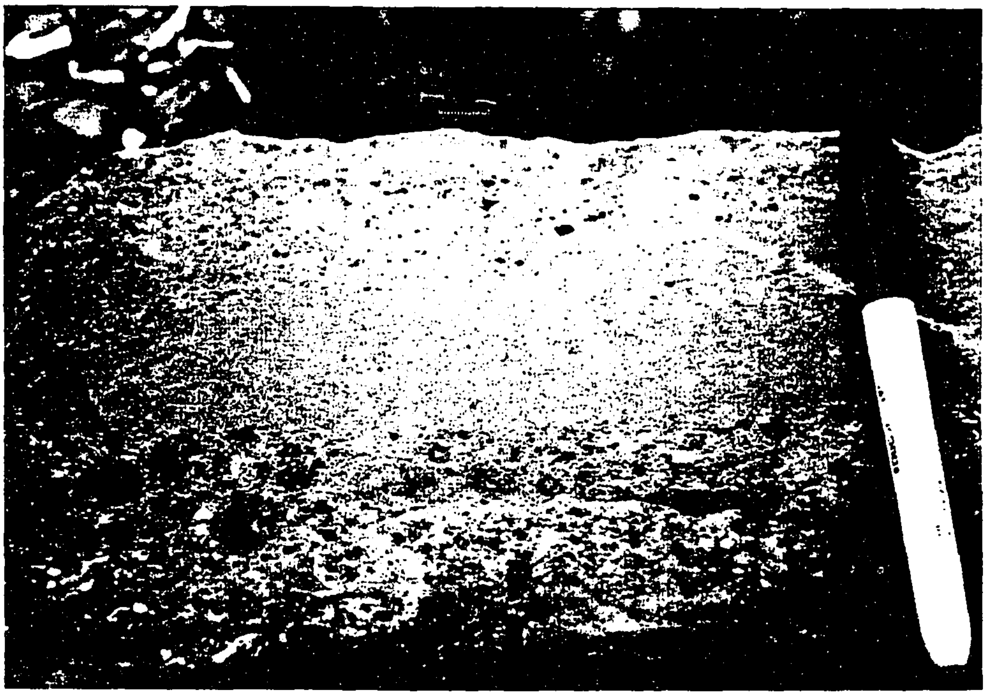


Figure 8.7 Sandstone lithofacies, Mangaqtaaq formation. Mixed bedload of abraded oncoids and terrigenous clasts abruptly overlain by cross-bedded(?) and ripple cross-laminated sandstone. Pen for scale (14 cm).

internal sedimentary structures, but both symmetrical and asymmetrical ripples are locally evident on bed surfaces. Mud drapes locally cover some surfaces.

8.A.2.b. Depositional interpretation

A local provenance is indicated for the components of the sandstone lithofacies. The composition and coarse grain size of angular to subrounded chert sand and pebbles suggest erosion from the chert arenites of the underlying Ulungarat formation and the radiolarian chert of the Romanzof chert. The carbonate grains indicate intraformational erosion from the algal limestone lithofacies.

The sandstone beds record deposition by shallow streams and unchannelized flow with sufficient energy to transport terrigenous sands into the area, to erode and abrade intrabasinal grains, and to mix these components. Fining-upward sandstone beds above erosional bases indicate deposition from decelerating traction currents. Where sandstone beds are thin, laterally continuous, and lack internal structures, they record unchannelized flow over large areas. Such flow may represent sheetfloods (Allen and Collinson, 1986), subaqueous storm deposits (Walker, 1985), or unstratified aeolian sheet sands (Eyles and Eyles, 1992). Where they are in close proximity to alluvial fans, sheet floods deposit horizontally- and wavy-laminated sandstone beds that in shallow water may be reworked by wave action (Allen and Collinson, 1986). Unstratified aeolian sheet sands may also be reworked by shallow water in the shore zone.

Cross-stratified, channelized sandstone bedsets 1 to 3 m thick suggest deposition by shallow streams. Asymmetrical and symmetrical ripple cross-lamination suggests deposition from decelerating flows and subsequent reworking by shoaling waves. The short wavelength of the symmetrical ripples indicates shallow-water reworking of the uppermost sand. The presence of mud drapes over rippled sandstone beds indicates fluctuations in energy, with mud deposited from suspension under relatively quiet-water conditions.

Ooids have been recognized only in the sandstone lithofacies, and their source has not been found. Ooid grainstones forming today in Lake Tanganyika form on flat shallow-water platforms in a zone of daily wave agitation (Cohen and Thouin, 1987), but they can also occur in hypersaline marine environments. The presence of ooids suggests that ooid shoals were located nearby.

The sandstone lithofacies is interpreted to have been deposited in or near a shore-complex environment (fig. 8.8). The presence of sandstone beds filling channels cut into shallow-water algal limestone suggest that streams and episodic unchannelized flows crossed the subaerial shore complex, eroding black intraclasts and other grains from the exposed algal flats and mixing with terrigenous clasts transported in from adjacent highlands. Erosion and reworking of sediment within the shore complex may have been caused by fluctuation in water level and/or storm generated waves and currents.

8.A.3. Black Mudstone Lithofacies

8.A.3.a. Description of black mudstone

The black mudstone lithofacies consists of black, calcareous, finely laminated and interbedded mudstone and siltstone. In the lower 80 to 100 m of the Mangaqtaaq formation at the type section, intervals of black mudstone and lesser siltstone are interbedded with algal limestone and sandstone and vary in thickness from a few centimeters to 300 cm. Contacts with underlying and overlying intervals of sandstone and algal limestone are sharp.

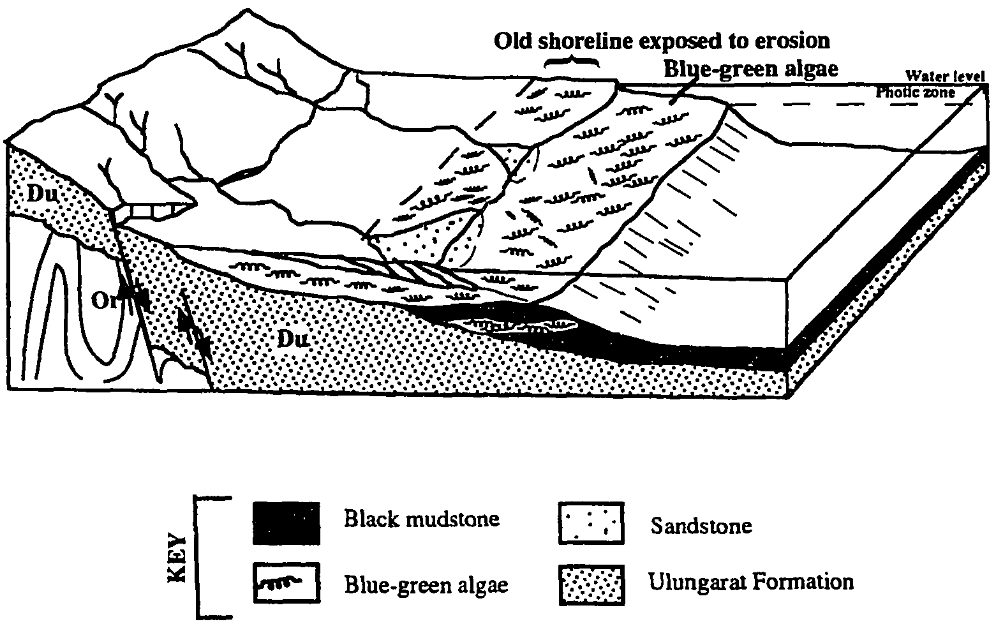


Figure 8.8. Schematic reconstruction of environment of formation and deposition of Mangaqtaaq formation during low-stand. During low-stands, the old shore zone is exposed to erosion by streams and unchannelized flow, which deposit a mixed bedload of chert and carbonate clasts. Romanzof chert (Or) and Ulungarat (Du) formation .

In the upper 90 m of the succession, black, finely laminated, recessive-weathering mudstone and siltstone are interlaminated on the scale of 2 to 4 mm. The contact of this thick interval with the underlying algal limestone lithofacies is sharp and planar. In contrast with the thin mudstone in the sandstone lithofacies, no plant fossils have been recovered from this interval.

8.A.3.b. Depositional interpretation

The lack of definitive sedimentary structures precludes determination of whether the rhythmic alternation of the mudstone and siltstone represents varves or thin, distal turbidites. Preservation of lamination indicates that the area was free of bioturbation and, together with the black color, suggests anaerobic conditions. The fine grain size, laminations, and black color are consistent with deposition in relatively quiet, stagnant bottom waters free of bioturbation where stratification of the water column caused bottom waters to become anaerobic (Heckel, 1972; Potter et al., 1980; Allen and Collinson, 1986). The carbonate to black mudstone cycles in the lower half of the formation may be the record of regressions in response to periods of increased carbonate production or of fluctuations in water level. In the upper half of the formation, deposition of this lithofacies over the shallow-water algal limestone lithofacies suggests deepening, with the sharp lower contact marking a transgressive flooding surface.

8.A.4. Pebbly Sandstone Lithofacies

8.A.4.a. Description of pebbly sandstone lithofacies

The pebbly sandstone lithofacies consists of pebbly sandstone and sandstone interbedded within the thick interval of black mudstone lithofacies in the upper part of the formation. This lithofacies is present only in the western part of the Aichilik pass thrust sheet. Contacts with the black mudstone are abrupt. Clasts are subangular to angular chert.

A thick localized interval of pebbly sandstone and coarse-grained sandstone beds 40 to 60 m thick is exposed 1.5 km west of the type section (fig. 8.3; Appendix H, measured section 90A-21). The base of this interval overlies a recessive-weathering covered zone several meters thick. The pebbly sandstone interval is present at the same stratigraphic position as the upper thick black mudstone interval, but the actual lateral transition into the black mudstone is covered by modern scree deposits.

Farther west, uncommon sandstone intervals 2 to 10 m thick are interbedded in the black mudstone lithofacies of the Aichilik pass thrust sheet. In this area there is no lower succession of cyclic interbedded algal limestone and 140 to 160 m of black mudstone directly overlies the Ulungarat formation (fig. 8.5). Three sandstone intervals are present in the black mudstone lithofacies above the Ulungarat type section. The lowest sandstone interval is a 2 to 3 m thick sand that consists of thin-bedded, fine- to medium-grained sandstone showing asymmetrical ripple cross-lamination with mud drapes.

The second sandstone interval is 12 m above the first. This interval is laterally continuous for a distance of approximately 300 m before being covered by modern talus deposits. The interval is 3 to 4 m thick and consists of a series of sandstone beds separated by mudstone 2 to 3 cm thick. Each 0.5 m thick bed has an erosional base and internally fines upward with asymmetrical ripples at the top. No internal sedimentary structures are visible. Uncommon inclined burrows are present.

A calcareous sandstone interval 2 m thick is present 20 to 30 m higher. This interval contains parallel laminae and a sandstone dike 0.5 m wide that internally shows dish structures. Thin beds of algal limestone lithofacies are present above this interval.

8.A.4.b. Depositional interpretation

Where the pebbly sandstone lithofacies is thick and localized, the limited distribution suggests a point source of repeated coarse-grained sediment influx. The angular to subangular clasts indicate proximity to a possibly tectonically active source. One and one-half kilometers west of the type section, the shore complex is overlain by pebbly sandstone that interfingers(?) laterally with black mudstone (fig. 8.5). The abrupt influx of pebbly sandstone coincides with an inferred abrupt deepening of the basin, suggesting that they are genetically related. This relationship is consistent with basin-margin faulting causing relative subsidence of the basin synonymous with erosion of new topographic highs. Additionally or alternatively, a change to a wetter climate would both raise the water level in the basin and increase erosion of nearby highlands.

Farther west, the thinner sandstone intervals interbedded low in the thick black mudstone lithofacies record deposition of sands alternating with deposition of mud from suspension. Lack of visible internal sedimentary structures prevents interpretation of the mechanism of deposition for the lower sands. Parallel laminae preserved in the upper sandstone interval suggest upper flow-regime deposition. Sandstone dikes are caused by fluidized intrusion of sand in response to pressure caused by the weight of overlying sediments or hydrostatic pressure (Reineck and Singh, 1980, p. 58). Dish structures are a response to rapid dewatering of the sandstone. Together, upper-flow regime deposition of sands, the sandstone dike, and dish structures within the thick black mudstone unit suggest rapid subaqueous deposition.

8.B. CYCLICITY

Cyclic alternation of black limestone and lesser sandstone with black mudstone indicates repeated change in depositional environment. Sharp contacts of the black mudstone lithofacies with the other lithofacies indicate abrupt changes. The cyclic character of the lower half of the formation at the type section is defined by alternating intervals of 1) black mudstone lithofacies with 2) thick algal limestone with interbedded channelized sandstone and laterally extensive thin-bedded sandstone. The thin (< 10 m) cycles in the lower half of the formation indicate these abrupt changes in depositional environment occurred frequently in the early history of the basin.

An abrupt upward change from black mudstone lithofacies to algal limestone lithofacies suggests a rapid change from stagnant anaerobic environment to a shallow-water algal flat environment. If the black shales represent deeper water deposits then this implies a rapid shallowing. Significant fluctuations in water levels of hydrologically closed basins occurring over short periods of time have been reported for modern African lakes (Johnson et al., 1987; Scholz et al., 1993).

The abrupt upward change from algal limestone lithofacies to black mudstone lithofacies also marks an abrupt change from shallow water limestone to stagnant low-energy conditions. In modern Lake Turkana (Africa), algae grow in proximity to turbid water flowing into the lake from rivers (Abell et al., 1982). This suggests that the cause of the abrupt change was not turbid water conditions, but rather a response to a rapid rise in water level that drown the algal-flats to below the photic zone.

8.C. AGE

The Mangaqtaaq formation is Late Devonian and/or Early Mississippian in age based on plant fossils within the lower part of the unit and its stratigraphic position. Abundant plant fossils are present in black mudstone interbedded with or overlying sandstone beds in the lower 20 m of measured section at location C (Plate 1). Plant fossils include Sporangia, reminiscent of *Tetrasylopteris* , indicating a Late Devonian to Early Mississippian age (S. Mamay, U.S. Geological Survey, written communication, 1989). The age of the Mangaqtaaq formation is also bracketed by the overlying Mississippian (Tournaisian) Kekiktuk Conglomerate and the underlying Middle to Late(?) Devonian Ulungarat formation.

8.D. DEPOSITIONAL SETTING

The Mangaqtaaq formation records deposition in a hydrologically closed basin. Shallow-waters along the margin of this basin were colonized by algal stromatolites and oncoids which contained a depauperate fauna of ostracods and gastropods. Low-energy deeper-water deposits are black laminated shales that indicate restricted anaerobic bottom conditions. Limestone containing blue-green algae, a depauperate fauna, and black shales that indicate anaerobic bottom waters support this interpretation. It is unclear whether the depositional setting was lacustrine or restricted marginal marine. Abundant plant fossils, absence of conodonts or any other definitive marine fauna, and blue-green algae are consistent with either lacustrine or very restricted shallow-marine conditions. A lacustrine interpretation is supported by the lack of definitive marine fauna, stratigraphic position between fluvial deposits, and limited lateral extent of the unit. The lacustrine interpretation is further supported by the abundant and abrupt lithofacies changes.

Modern and ancient lake deposits are characterized by abrupt lateral and vertical facies changes (Platt and Wright, 1991). Although a lacustrine interpretation seems to best explain the relationships, the alternative hypothesis of a restricted marine environment is also presented.

8.D.1. Lacustrine Interpretation

Within the Mangaqtaaq formation, two contrasting depositional environments formed due to apparent differences in water depth: a shore complex and deeper-water deposits. The shore complex includes a variety of subenvironments that reflect changing conditions that fluctuated both laterally and with time. Shallow, quiet water occupied by blue-green algae (stromatolites and oncoids) and a restricted fauna are recorded by the algal limestone lithofacies. Lacustrine stromatolites occupy the shoreline and nearshore environments in modern mixed carbonate - siliciclastic lakes (Jones and Wilkinson, 1978; Osborne et al., 1982), and have been interpreted to occupy the same environment in the ancient record (Casanova, 1986).

Together, the algal limestone lithofacies and the sandstone lithofacies suggest a shoreline with fluctuating energy conditions. During lowstands, the algal flat was subaerially exposed and mixed terrigenous and intraformational sands were deposited in shallow channels and as unchannelized beds. Erosion of the shore complex may have been caused by storms or by exposure of algal subenvironments due to lower water level in the lake.

Interpretation of the algal limestone lithofacies as ancient shoreline deposits and the black mudstone lithofacies as deeper-water deposits implies that each of the sharp contacts between the limestone lithofacies and the interbedded mudstone lithofacies records a deepening event. This repetitive pattern is interpreted to be a response to the lateral shifting of lithofacies as water level rose and fell, recording contraction (low-stands) and expansion (high-stands) of the lake (fig. 8.8 and 8.9). These relationships suggest a periodic cause, perhaps fluctuations in lake level induced by climatic and/or tectonic changes. Large lake-level fluctuations with associated erosion surfaces during low-stands are characteristic of lakes in modern rift environments where the fluctuations occur in response to climatic changes (Johnson et al., 1987; Scholz et al., 1990). In the Triassic - Jurassic Newark Supergroup cyclic lacustrine deposits are also interpreted to be a response to climatic change (Smoot and Olsen, 1988). In the Mangaqtaaq formation, the 3 to 10 m thick cycles in the lower half of the formation may be a response to fluctuations in water level controlled by climate, rate of sedimentation controlled by climate or tectonics, and/or basin subsidence.

The thin, apparently higher-frequency cycles of the lower half of the formation ended abruptly with a long-term change recorded by the thick black mudstone at the top of the formation. This major interval of lake high-stand deposits includes local deposits of coarse-grained clastic detritus and of rapidly deposited sandstone beds. This is evidence that coarse clastic material continued to be supplied to the basin at a local point source. Less common, thin sandstone beds must have been transported into deeper parts of the lake by sediment gravity flows. This could be explained by periods of increased rainfall that would both increase the rate of erosion from surrounding highlands and raise the water level of a lake. Alternatively, or concurrently, tectonically uplifted highlands peripheral to the basin could have served as the source of the terrigenous clastic detritus.

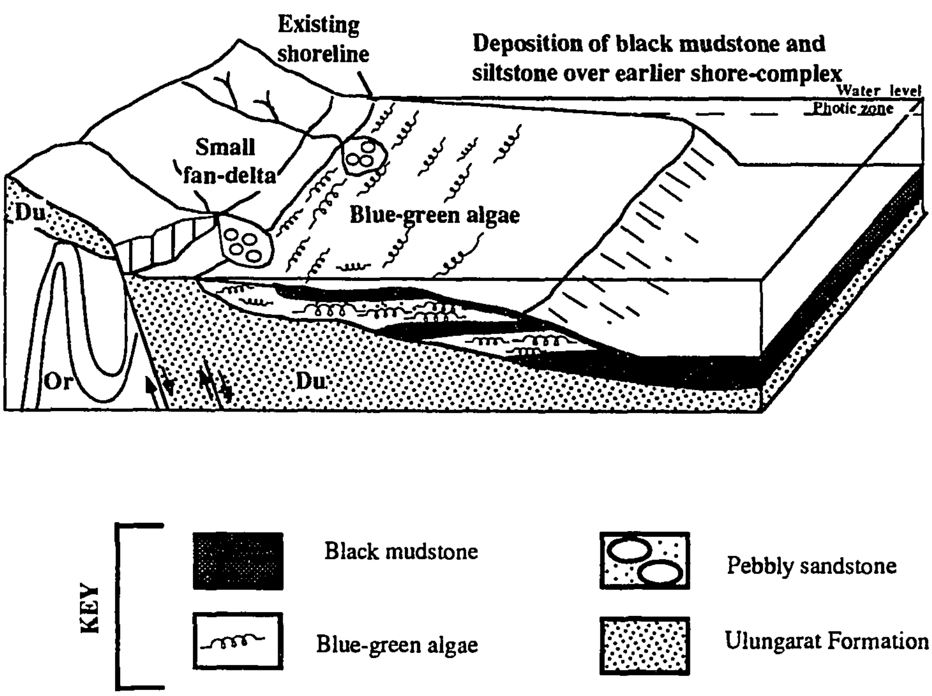


Figure 8.9. Schematic reconstruction of environment of deposition of Mangaqtaaq formation during high-stand. Black siltstone and mudstone are deposited over earlier shallow-water shore complex dominated by blue-green algae. Romanzof chert (Or) and Ulungarat formation (Du).

8.D.2. Restricted Marine Interpretation

The Mangaqtaaq formation also could be interpreted to record deposition in a restricted shallow-marine setting. In a marine setting, the cyclic alternation of the algal limestone lithofacies with the black mudstone lithofacies could have resulted from repeated relative sea-level fluctuations. The sharp contacts between the two lithofacies indicate rapid relative change in sea level.

Short-term, rapid sea-level changes can result from local tectonic or glacio-eustatic mechanisms. Local tectonic control would require some mechanism of "yo-yo" uplift and subsidence, but it is difficult to envision a tectonic setting where such rapid uplift and subsidence occur. Rapid sea -level change could be a response to glacio-eustatic rises and falls as discussed by Reading (1987). Glacioeustatic sea-level changes might explain the cyclicity with the black shales representing high-stand deposits and limestone and associated sandstone beds representing low-stands. However, the basin would need to be connected to the world ocean via some restricted passage, possibly representing a small embayment.

9. KEKIKTUK CONGLOMERATE

The Kekiktuk Conglomerate is an upward-fining and thinning succession of chert and quartz pebble to cobble breccia and conglomerate, fine- to coarse-grained sandstone, and interbedded black shale. In the study area, the formation contains coal, petrified wood, Early Mississippian plant fossils, and ranges in thickness from zero to 200 m. The lower contact is an angular unconformity. In the west fork valley succession to the north, the Kekiktuk Conglomerate overlies the Ordovician Romanzof chert with high-angle discordance, whereas to the south, in the continental divide succession, it overlies the Ulungarat formation or, locally, the Mangaqtaaq formation, with low-angle discordance. The upper contact is gradational with and intertongues with black mudstone and siltstone of the Kayak Shale. Correlation of the breccia, conglomerate, and sandstone of the west fork valley succession with the conglomerate and sandstone below the Kayak Shale in the continental divide succession and assignment to the Kekiktuk Conglomerate is based on lithologic similarity, the presence of distinctive purple-raspberry colored chert clasts in both areas, and stratigraphic position below the Kayak Shale.

9.A. DESCRIPTION

The Kekiktuk Conglomerate is compositionally similar throughout the study area. The breccia and conglomerate include gray, white, black, and purple-raspberry colored chert clasts with less common quartz clasts. Only locally are quartz pebbles and cobbles prominent. Radiolarian ghosts are common in the chert clasts. Within the sandstone, the relative abundance of chert and quartz grains changes abruptly both laterally and vertically without a systematic pattern. The proportion of quartz verses chert grains in sandstone is variable, with no systematic compositional pattern. Breccia, conglomerate, and coarse-grained sandstone are typically cemented with equant to bladed megaquartz with crystals increasing in size toward the center of the former interstitial voids. Medium- to fine-grained sandstone is cemented with quartz overgrowths.

9.A.1. West Fork Valley Succession

9.A.1.a. Description

In the west fork valley succession, where the formation directly overlies Ordovician Romanzof chert, intervals of the Kekiktuk Conglomerate are laterally discontinuous and generally less than 15 m thick (fig. 9.1 and 9.2). This succession is variable in lithologic composition, thickness and sedimentary organization. Local relief on the erosional surface of the underlying unconformity is 10 to 15 m. Locally, steep zones containing north-dipping fractures in the Romanzof chert mark changes in relief on the unconformity surface. Beds of Kekiktuk Conglomerate fill lows on the unconformity surface, but are not offset above the fractures. These relationships indicate that the fractures pre-date the Kekiktuk Conglomerate and influenced erosion of the surface or, alternatively, that syndepositional high-angle faulting occurred during deposition of the Kekiktuk Conglomerate.

Locally, poorly sorted, matrix-supported chert breccia characterizes the basal deposits, where deposition of the Kekiktuk Conglomerate occurred along the edges of these chert topographic highs. The mudstone matrix of the breccia has a flow texture around individual chert grains suggesting deformation of the matrix by compaction.

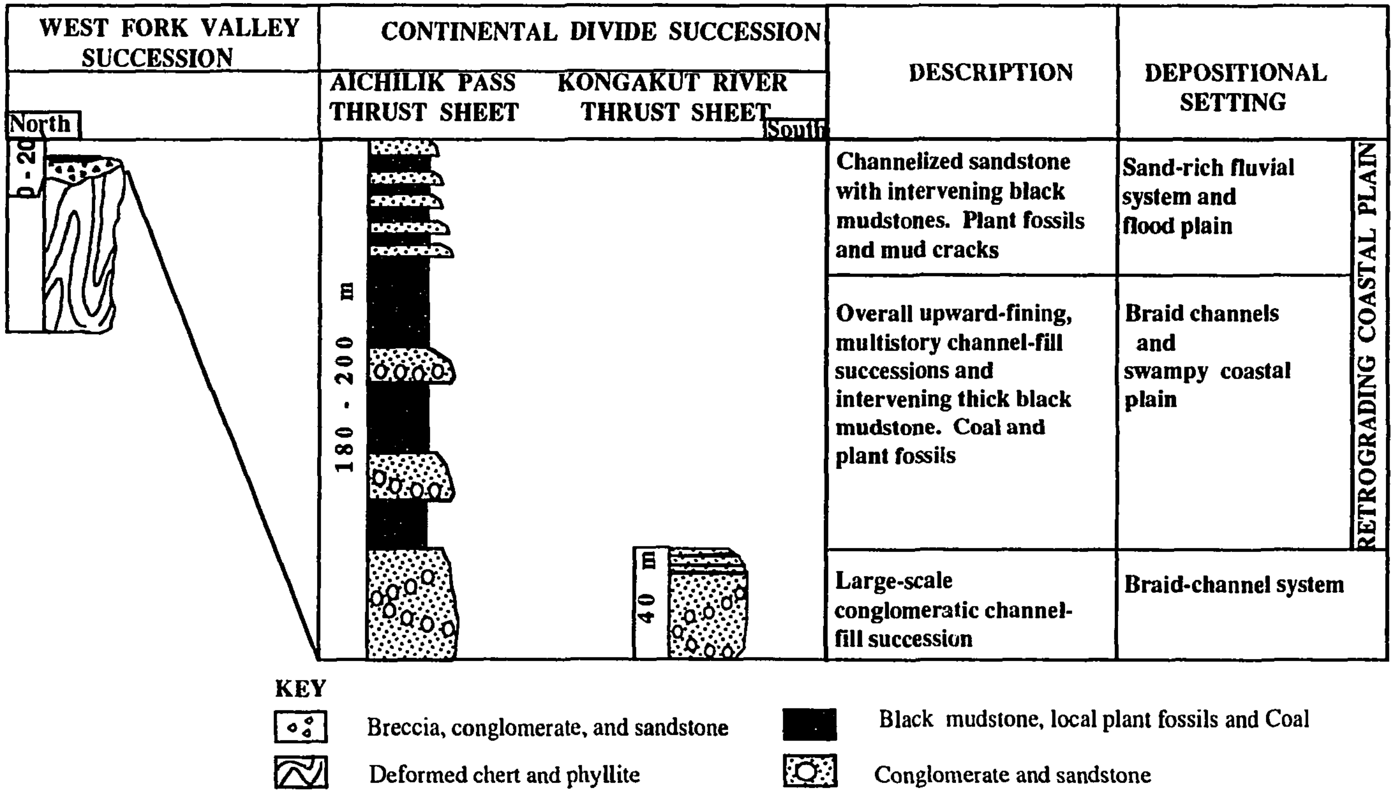


Figure 9.1. Generalized stratigraphic columns showing north to south change in the Kekiktuk Conglomerate. The Kekiktuk Conglomerate is unconformable at the base and is conformably overlain by the Kayak Shale. See Appendix H for detailed measured sections.

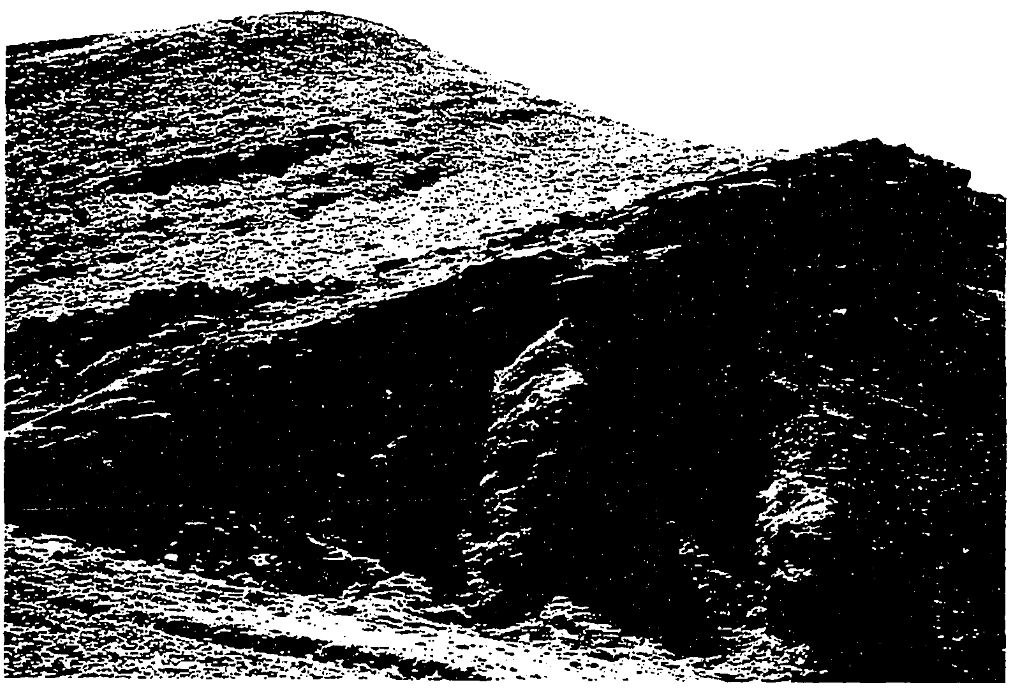


Figure 9.2. Kekiktuk Conglomerate in the west fork valley succession. The underlying Romanzof chert is sub-perpendicular to the Kekiktuk Conglomerate. Lowermost ledge of Kekiktuk Conglomerate is 5.5 m thick. For detailed description refer to measured section 90A-25, Appendix H.

Locally, these breccias overlie black mudstone containing plant fossils. The basal chert breccia usually becomes conglomeratic within one meter above the base, fines upward to fine-grained sandstone and siltstone, and is overlain by black mudstone with silicified burrows and abundant plant fossils.

Thin, isolated (less than 15 m thick by 10 to 20 m across), lenticular conglomerate and sandstone intervals occur elsewhere along the underlying erosional unconformity. Characteristically, these deposits are massive, horizontal to trough cross-stratified, texturally mature conglomerate and sandstone with small sandstone lenses (6 by 50 cm). Conglomeratic beds, 50 to 100 cm thick, commonly fill channels cut into underlying conglomerate beds. Above the basal conglomeratic beds, the Kekiktuk Conglomerate fines upward to fine-grained sandstone overlain by black mudstone containing plant fossils and coal.

9.A.1.b. Depositional interpretation

The relationship of the character of Kekiktuk deposits to paleorelief on the unconformity surface suggests that deposition was controlled by paleohighs of Romanzof chert which were both a sediment source and barrier to lateral migration (fig. 9.3). Angular chert clasts of the same composition as the nearby Ordovician chert paleohighs suggest local derivation; whereas the deformed muddy matrix indicates either deposition of the breccia in debris flows or as colluvium deposited on a soft muddy substrate that flowed upward. The more texturally mature conglomerate and sandstone beds were deposited in small fluvial channels above the unconformity surface. Horizontal to trough cross-stratified pebble conglomerate beds filling channels cut into underlying conglomerate beds are consistent with bars and in-channel sinuous-crested bedforms

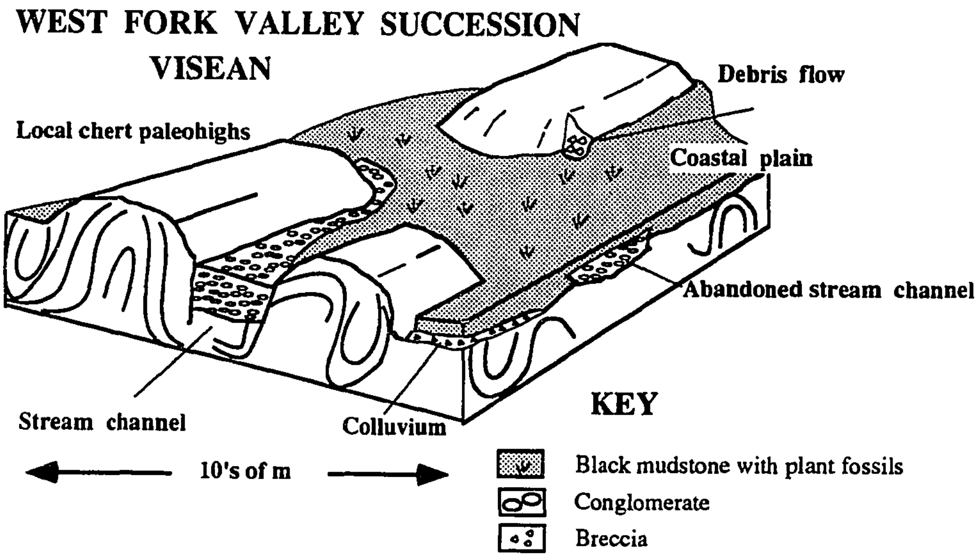


Figure 9.3. Schematic diagram illustrating depositional setting of the west fork valley succession. Channelized sandstone and debris-flow deposits of the Kekiktuk Conglomerate interfinger laterally with swampy coastal-plain deposits of the Kayak Shale.

(Miall, 1977). Interbedded sandstone lenses are consistent with sand deposition during falling flood stage (Rust, 1972). The fining-upward succession at the top of these deposits indicates waning-flow conditions that, together with the overlying mudstone, plant fossils, and coal, record abandonment of the channel. The laterally discontinuous beds, deposition controlled by relief on the underlying unconformity, and derivation of clasts from the underlying Romanzof chert suggest localized deposition. The shallow channels, colluvium, and debris-flow deposits closely associated with coastal-plain deposits of the Kayak Shale (discussed in chapter 10) document rapid marine transgression over the earlier source area.

9.A.2. Continental Divide Succession

9.A.2.a. Aichilik pass thrust sheet

Kekiktuk Conglomerate and intertonguing(?) black Kayak Shale are 180 to 200 m thick in the Aichilik pass thrust sheet. Each of four conglomerate and sandstone intervals overlies and is in turn overlain by black siltstone and mudstone interpreted to be Kayak Shale. Each successive conglomerate and sandstone interval is thinner and finer grained than the one below. Although these multiple intervals of the Kekiktuk Conglomerate could be interpreted to reflect structural duplication, the progressive vertical change in organization as the overall succession fines and thins upward suggests that the overall relationship is depositional. These relationships are shown in figure 9.1.

The lower three conglomerate and sandstone intervals are laterally extensive, tabular, elongate bodies. Each successively higher interval is thinner and contains less conglomerate. Above a basal scour, each interval consists of multistory, amalgamated, clast-supported conglomerate beds that are massive to trough cross-stratified with an upward decrease in scale of trough cross-stratification and an accompanying change from conglomerate to pebbly sandstone. Above the basal conglomerate beds, low-angle, cross-stratified, fine-grained sandstone continue the fining-upward trend into horizontally stratified siltstone beds. Interbedded mudstone near the top of the intervals contains plant fossils and coal.

The uppermost of the four intervals is composed of chert granule to pebble conglomerate, chert arenite, and siltstone in fining-upward cycles in an overall fining-upward succession. Each fining-upward cycle is 1 to 3 m thick with a concave-upward base that truncates underlying gray to black siltstone and mudstone. Chert-pebble conglomerate and coarse-grained sandstone beds fine upward to asymmetrical ripple cross-laminated, fine-grained sandstone and siltstone beds. Between channelized successions, intervening siltstone and mudstone contains mudcracks and plant fossils.

9.A.2.b. Kongakut River thrust sheet

Cliff-forming, multistory and multilateral, amalgamated conglomerate and sandstone cycles, in an overall fining-upward succession 40 m thick, characterize deposits of the Kekiktuk Conglomerate in the Kongakut River thrust sheet and in southwestern exposures of the Aichilik pass thrust sheet (fig. 9.4). The succession unconformably overlies the Ulungarat formation and is in turn conformably overlain by the Kayak Shale. The basal unconformity is well exposed, with underlying beds dipping less than 5° more steeply to the south than overlying beds.

The lower 30 m is characterized by conglomerate and sandstone cycles 2 to 3 m thick (fig. 9.5) and by coarse- to medium-grained tabular sets of planar cross-stratified sandstone beds 2 m thick. Internally, each conglomerate and sandstone cycle begins with

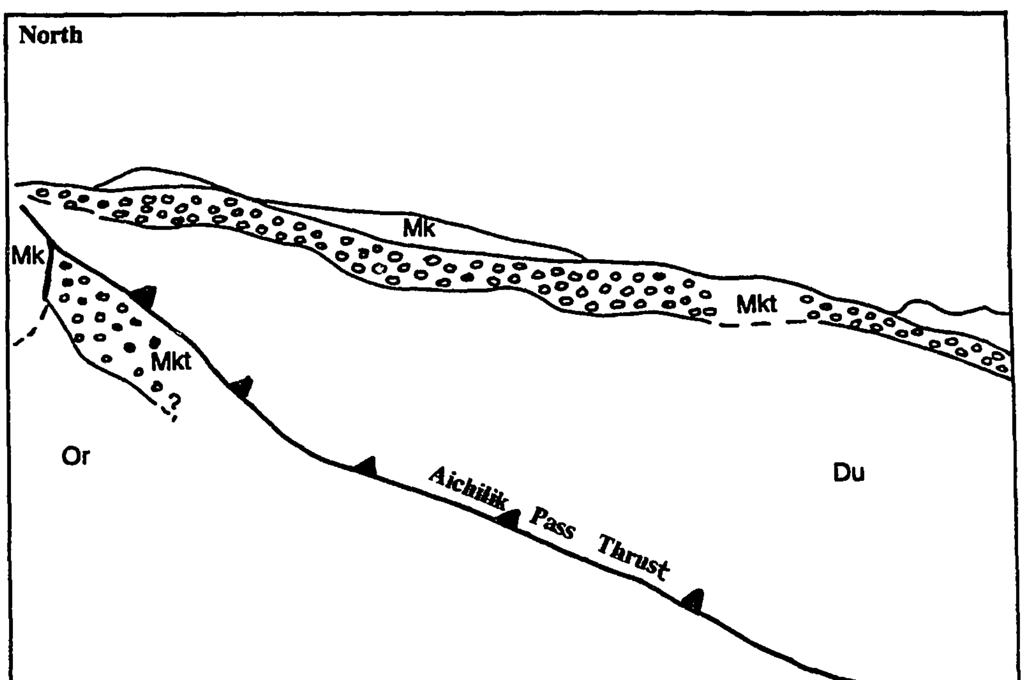


Figure 9.4 Kekiktuk Conglomerate in the southwestern Aichilik pass thrust sheet. High ridge is capped by 40 m thick succession of multistory and multilateral braided stream deposits. Line drawing shows geologic relationships. For detailed description refer to measured sections 89A-118, 89A-129, and 89A-131, Appendix H. Aichilik pass thrust (APT), Romanzof chert (Or), Ulungarat Formation, (Du), Kekiktuk Conglomerate (Mkt), Kayak Shale (Mk).

Figure 9.5. Detail from cliff shown in figure 9.4 showing base of a multistory conglomeratic channel-fill succession. Lower part of measured section 89A-129, Appendix H.

clast-supported, moderately sorted, chert pebble and cobble conglomerate. Conglomerate beds are massive to horizontally stratified, and crudely fine upward. The conglomerate is overlain in some places by trough cross-stratified pebbly sandstone beds 8 to 10 cm thick. The top of each cycle consists of plane-bedded, fine-grained sandstone beds. Commonly, only the lower conglomeratic part of each cycle is preserved beneath the conglomerate-filled erosional scour at the base of the next overlying cycle.

Well-developed fining-upward cycles 0.5 to 2 m thick characterize the upper 10 to 15 m of the succession. The cycles begin with a thin basal conglomerate or pebbly sandstone that is overlain by large-scale trough cross-stratified, medium- to fine-grained sandstone beds 20 to 50 cm thick. The top of each cycle consists of ripple cross-stratified and horizontally bedded sandstone and siltstone beds that are abruptly overlain by thin, organic-rich siltstone beds with plant fragments. The conformable upper contact with the overlying Kayak Shale is an undulating, planar surface. Abundant plant fossils are present along this surface.

9.A.2.c. Depositional interpretation

To the south, in the Kongakut River thrust sheet, the tabular, elongate geometry of the Kekiktuk Conglomerate is consistent with deposition by the lateral movement of a braided channel complex as described by Cant (1978). Coarse grain size and internal organization of the deposits, combined with a lack of fine-grained suspension deposits, is consistent with proximal deposition in a braided fluvial system of the Scott to Donjek type described by Miall (1977). Studies of modern fluvial environments show that massive to horizontally stratified clast-supported gravels are common in braided stream systems and are commonly deposited in longitudinal and diagonal bars and in bar complexes (Rust, 1978). The large-scale, planar tabular cross-stratification is consistent with large, relatively straight-crested bedforms (Reineck and Singh, 1980; Collinson, 1986). Each of the conglomeratic cycles records in-channel and bar deposits overlain by sinuous crested dunes and ripples indicating falling-stage deposition. Together, the large tabular sets of planar cross-stratification and the conglomerate and sandstone cycles record deposition in a major braid-channel system. Near the top of the succession, the thinner- and finer-grained, fining-upward cycles are consistent with decreasing flow in individual channels (Williams and Rust, 1969; Rust, 1978).

To the north, in the Aichilik pass thrust sheet, the internal organization of successively higher Kekiktuk intervals record a change in fluvial style from braided systems to meandering systems. The lowermost of these intervals is similar in organization to the Kekiktuk Conglomerate on the Kongakut River thrust sheet. In the lower three intervals, the massive to horizontally stratified, clast-supported conglomerates and trough cross-stratified sandstone beds are consistent with deposition as longitudinal and diagonal bars and as bar complexes in a braided fluvial system (Williams and Rust, 1969; Rust, 1972; Rust, 1978). The fining-upward character of the upper part of each of these intervals records decreasing flow and may be a response to decreased sediment supply, channel avulsion (Elliott, 1986), decreasing gradient, and/or rising sea level. These deposits are the products of a fluvial system characterized by shallow channels and intervening bars with an upward change from a conglomerate-dominated system to a sand-dominated system.

The erosive bases and fining-upward cycles of the uppermost sandstone interval in the Aichilik pass thrust sheet are the record of waning-flow traction currents whereas the interbedded siltstone and mudstone with mudcracks are consistent with deposition from suspension in abandoned channels and flood plains. These deposits are interpreted to record migration of shallow meandering streams across a flood plain.

Intervals of siltstone and mudstone, 20 to 40 m thick, are present between the conglomerate and sandstone intervals (fig. 9.1). Abundant plant fossils and coal are present along contacts between sandstone intervals and overlying black mudstone. Although no marine fossils have been recovered, the black mudstone intervals are similar to mudstone of the Kayak Shale to the south and to the north. On this basis these intervals are interpreted to be Kayak Shale and are discussed in section 10.C. The alternation of thick mudstone intervals that are interpreted to be marine Kayak Shale with fluvial deposits suggests deposition in a coastal-plain setting. The lower, multistory braided-stream deposits are consistent with proximal braid-plain delta successions as described by Elliott (1986). Successively higher Kekiktuk tongues are thinner and finer-grained, recording an upward change from braided to meandering fluvial systems. These relationships suggest that the upward change reflects a lower stream gradient and decrease in accommodation in response to rising relative sea level. Similar vertical changes in fluvial style have been documented by Nami and Leeder (1978) for the Jurassic of northeastern England.

9.B. AGE

The Kekiktuk Conglomerate in the Kongakut River thrust succession is pre-Late or Late Tournaisian (early Mississippian) in age. This age is based on the Late Tournaisian age of the lowest interval of the overlying Kayak Shale. Plant fossils recovered from interbedded fine-grained intervals of the Kekiktuk Conglomerate and in the basal Kayak Shale throughout the study area are of Early Mississippian age (Robert

Spicer, University of Oxford, oral communication, 1991). The youngest rocks immediately beneath the basal Kekiktuk unconformity are those of the Mangaqtaaq formation, but their age is poorly constrained (Late Devonian or Early Mississippian).

9.C. DEPOSITIONAL SETTING

The change in organization from south to north suggests that the Kekiktuk Conglomerate records a northward-retrograding fluvial to marginal-marine system. Deposition in two distinctly different depositional settings is indicated by major differences in both thickness and depositional organization between the west fork valley succession to the north and the continental divide succession to the south. In the north, a thin succession of Kekiktuk Conglomerate fills local shallow-channels. To the south, a thick succession of conglomerate and sandstone accumulated above an older clastic wedge.

The braid-channel complex to the south records maximum grain size of Kekiktuk deposition in the study area. The braid-channel system was deposited with low-angle discordance over the Ulungarat and, locally, the Mangaqtaaq formations. The closest lithologically similar source for these sediments is the Ordovician Romanzof chert which underlies the sub-Kekiktuk unconformity to the north (west fork valley succession).

To the south (Kongakut River thrust sheet), a single thick interval of braid-channel deposits is overlain by black mudstone and siltstone of the Kayak Shale, indicating that transgression resulted in early demise of the fluvial system here. The intertonguing succession of black Kayak mudstone and fining-upward channelized sandstone intervals in the central part of the field area (Aichilik pass thrust sheet) record migration of a retrograding fluvial system across a swampy delta plain or, alternatively, progradational pulses in a retrograding fluvial - deltaic system. Rising base level as a result of northward transgression caused the majority of coarse-grained clastic sediments to be deposited on the delta plain and not transported into the off-shore marine setting.

In the north (west fork valley succession), where the Kekiktuk Conglomerate was deposited with high-angle discordance over the Romanzof chert, it is characterized by thin, laterally discontinuous colluvium deposits, small debris-flow deposits, and deposits of small, coarse-bedload streams. The black mudstone with plant fossils and coal that underlies, interfingers laterally with, and overlies the coarse-grained deposits is interpreted to be swampy flood-plain deposits. Kekiktuk deposition in this area may have been synchronous with transgression and deposition of Kayak Shale. Rising relative sea level resulted in transgression over the previous source area, cutting off the sediment supply, and ending coarse-grained terrigenous clastic deposition. The record of Kekiktuk deposition in the north is distinctly different from the record of Kekiktuk deposition in the continental divide succession. The differences suggest an abrupt change in relief and accommodation between the west fork valley and continental divide successions. The thicker succession to the south reflects greater accommodation, perhaps due at least in part to subsidence. The thin succession to the north and absence of Middle Devonian and younger deposits beneath the sub-Kekiktuk unconformity reflects less accommodation and higher elevation, either as a stable or actively uplifted topographic high.

10. KAYAK SHALE

The Kayak Shale is micaceous, dark-gray to black, organic-rich, very finely fissile, are locally silty. Beds of sandstone and argillaceous limestone locally occur within the black shale. Ironstone nodules, pyrite, and coal are locally present. Abundant organic matter consisting of woody and coaly material occurs throughout the succession. Grazing traces of the ichnofossil *zoophycus* are locally common in black mudstone. Rare scolecodonts (jaw apparatus of annelid worms) have been recovered from the shale (J. Utting, Geological Survey of Canada, written communication, 1991).

Significant lateral facies variations characterize the lower Kayak Shale. Abrupt changes in composition and organization coincide with a three-fold increase in thickness toward the south. Original depositional thicknesses are uncertain because of ubiquitous deformation and associated structural thickening within the unit. To the north, in the west fork valley succession, the formation is less than 100 m thick and composed of black shale with interbedded argillaceous limestone in the upper part. To the south, in the continental divide succession, the formation is 300 to 400 m thick and includes intervals of sandstone and argillaceous limestone within the black shales.

The Kayak Shale conformably overlies, and locally intertongues(?) with, the Kekiktuk Conglomerate. The upper contact is gradational with the overlying platform carbonates of the Lisburne Group.

10.A. DESCRIPTION OF LATERAL VARIATION

10.A.1. West Fork Valley Succession

10.A.1.a. Description

In the north, where the Kayak Shale is less than 100 m thick, the basal 20 m consists of black mudstone and local siltstone that fills in paleotopographic lows with relief up to 15 m, on the surface defined by the top of the underlying Romanzof chert or Kekiktuk Conglomerate. The formation locally onlaps and directly overlies Ordovician chert that formed paleotopographic highs throughout Kekiktuk and lower Kayak deposition (fig. 9.3). Thin, laterally discontinuous deposits of Kekiktuk Conglomerate are present in paleotopographic lows between the underlying Romanzof chert and overlying black shales. Abundant plant fossils, local thin coals, and siltstone intervals are present within the black mudstone of this basal interval.

Locally, uncommon sandstone beds overlie 10 to 15 m of basal black mudstone containing abundant plant fossils. These siltstone to fine-grained sandstone beds are interbedded with mudstone and form upward-coarsening intervals in an overall upward-thinning succession 4 to 5 m thick. Each interval is 1 to 1.5 m thick, has sharp lower and upper contacts, and is bounded by black shale. Within each interval, bioturbated siltstone alternates with sandstone and siltstone beds with low-angle cross-strata and ripple cross-laminae. Mud drapes some ripples. Elsewhere at this same stratigraphic position, medium-grained sandstone bodies, 3 to 6 m thick, are so intensely deformed that their internal sedimentary organization could not be determined.

Above these basal deposits, the Kayak Shale consists almost entirely of recessive-weathering organic-rich black mudstone. Argillaceous skeletal packstone intervals each less than 10 m thick are present just below the gradationally overlying Lisburne Limestone.

10.A.1.b. Depositional interpretation

Deposition of the Kayak Shale over Romanzof chert and thin, laterally discontinuous Kekiktuk Conglomerate suggests rapid transgression and drowning of this earlier source area. Deposition of the basal black mudstones around and over paleotopographic highs of Romanzof chert on the underlying surface suggest a low-energy, rocky coast. Black shale with abundant plant fossils and coal indicate that the initial deposits were in a stagnant, low-energy setting. Fine-grained, upward-coarsening sandstone intervals with sharp contacts, low-angle cross-strata, and ripple cross-laminae suggest deposition by traction currents (Harms et al., 1982), whereas bioturbation and mud drapes on ripples indicate fluctuating energy conditions and deposition from suspension. Together, these characteristics suggest deposition of the fine-grained sands in a sand-starved shoreface. Overall upward thinning of the succession may be due to a gradually decreasing supply of coarser-grained sediment, possibly in response to deepening water. These characteristics suggest attenuated delta-front sequences of a retrograding delta system similar to those described by Elliott (1986). The thick succession of black mudstone overlying the lower 20 m records deepening marine conditions.

10.A.2. Continental Divide Succession

10.A.2.a. Aichilik pass thrust sheet

In the Aichilik pass thrust sheet, silty black shale overlies and intertongues with nonmarine fluvial deposits of the Kekiktuk Conglomerate. Along contacts with the underlying intervals of fluvial sandstone, abundant plant fossils and thin beds of coal are present in the black shales. At the top of the Aichilik pass thrust sheet, the Kayak Shale is the detachment horizon for the overlying Kongakut River thrust. The thrust truncates the formation, therefore, original depositional thickness and complete succession of the Kayak Shale in this area are unknown.

10.A.2.b. Kongakut River thrust sheet

In the Kongakut River thrust sheet, 300 to 400 m of Kayak Shale abruptly overlie thick braid-channel deposits of the Kekiktuk Conglomerate. This succession is generally less silty than the Kayak Shale in the Aichilik pass thrust sheet. In this succession, the Kayak Shale is informally subdivided into lower, middle, and upper depositional units (fig. 10.1). This subdivision is based on differences in composition and organization of the interbedded deposits.

Lower depositional unit: The lower 100 m of the Kayak Shale is laterally variable. The dominant lithology is black mudstone that passes laterally into and encloses either argillaceous limestone or coarsening-upward intervals of sandstone.

A localized 30 to 40 m thick interval of gray argillaceous limestone consists of 2 to 3 cm thick beds of horizontally bedded skeletal packstone and lime mudstone. The packstone contains a diverse, normal-marine fauna that includes crinoids, bryozoans,

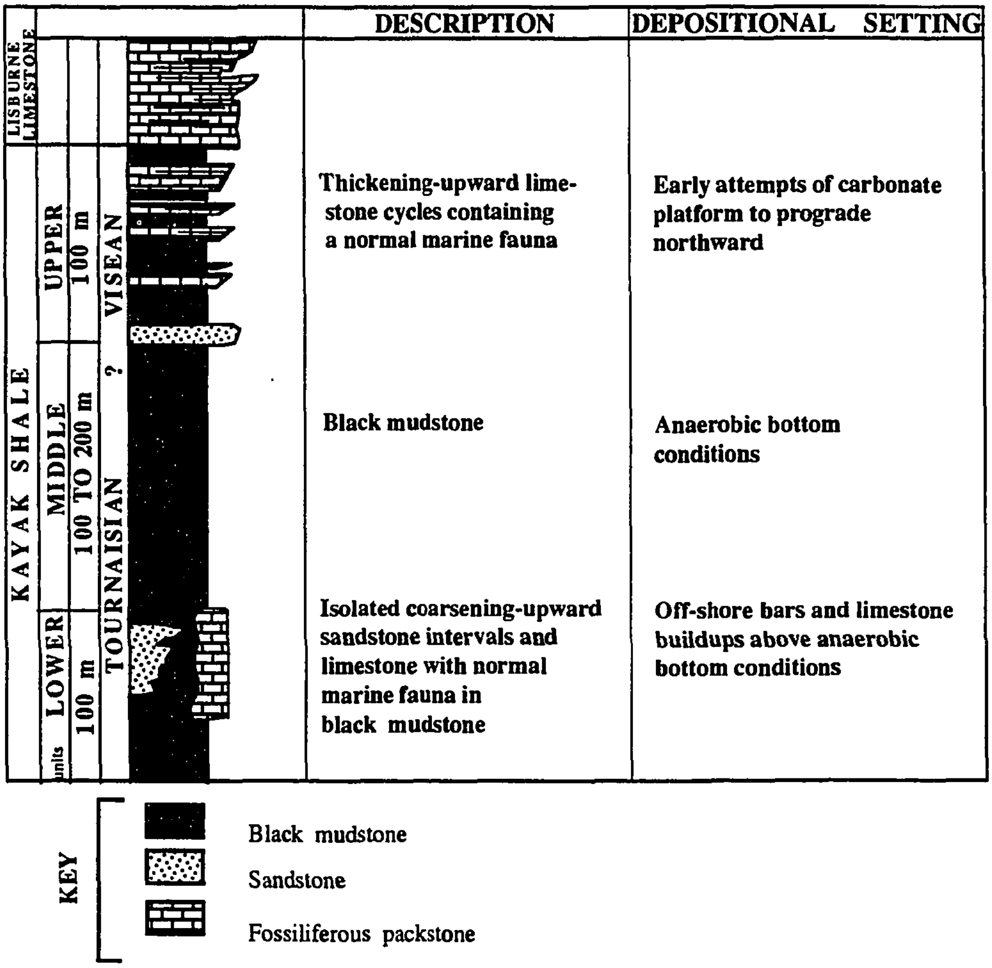


Figure 10.1. Generalized stratigraphic column of the Kayak Shale in the Kongakut River thrust sheet of the continental divide succession. See Appendix H, measured sections 90A-100 and 90A-131 for detailed measured sections of lower and upper Kayak Shale.

trilobites, brachiopods, colonial corals, ostracods, algae, forams, and sponge spicules. Micritization of grains is common. Locally, large, long (5 cm) articulated crinoid stems dominate the fossil assemblage. Elsewhere, the limestone beds consist of thin lenses of bioclastic packstone interbedded with lime mudstone. Packstone beds 1 to 2 cm thick have erosive bases, contain fossil fragments, fine-upward to tops with ripple cross-laminae, and are overlain by horizontally laminated black mudstone.

Elsewhere, but at the same stratigraphic position as the limestone intervals, sandstone and pebbly sandstone intervals 10 to 20 m thick extend laterally for 50 to 100 m. Tundra cover and poor exposures generally prevent description of the internal organization of these sandstone bodies or the character of the immediately underlying shales. Where locally exposed, the sandstone intervals have sharp lower contacts over black mudstone and coarsen-upward.

Middle depositional unit: The middle interval consists of 100 to 200 m of recessive-weathering, monotonous, organic-rich, black mudstone. Original depositional thickness is unknown, but folds with less than 10 m amplitude and 20 m wavelength indicate structural thickening. The base of the middle depositional unit is placed at the top of the uppermost limestone or sandstone interval in the lower Kayak Shale. The top is placed at the base of the lowermost sandstone or limestone interval in the upper Kayak Shale.

Upper depositional unit: The uppermost 100 m of the Kayak Shale is a cyclic succession of black shale and limestone beds that pass gradationally upward into the overlying platform carbonate rocks of the Lisburne Group. Locally, sandstone intervals occur below the alternating shale and limestone.

The basal sandstone bodies crop out laterally for a distance of 5 km. Sandstone bodies are 15 to 20 m thick and consist of coarse- to medium-grained sandstone beds 20 to 30 cm thick. Sutured bedding contacts, prominent fractures, and sets of vein-filled tension fractures obscure sedimentary structures. Some low angle cross-strata are visible. A thin siltstone and mudstone interval within the sandstone contains coal. The coal may have formed from non-transported plant material, suggesting deposition in a marginal, nonmarine setting. Alternatively, the coal may have formed from transported plant debris deposited in a marine setting.

Just below the base of the Lisburne Limestone, 80 to 100 m of laterally persistent, upward-thickening intervals of gray argillaceous skeletal packstone 1 to 10 m thick alternate with recessive-weathering, upward-thinning intervals of argillaceous lime mudstone (Appendix H, measured section 90A-130). The contact with the overlying Lisburne Group is gradational and is arbitrarily placed at the top of the uppermost black mudstone interval less than 5 m thick which is coincident with the base of the lowermost thick limestone interval. The number and thickness of individual limestone intervals vary laterally. It generally is not possible to trace a single limestone interval for more than 2 or 3 km. Packstone beds have a diverse, normal-marine fauna dominated by pelmatozoans and bryozoans. Ostracods, forams, calcispheres, sponge spicules, algae, trilobites, and brachiopods are also present. Internally, each thickening-upward interval consists of even to wavy beds, 2 to 15 cm thick, that have sharp lower and upper contacts. Ripple cross-laminae are present locally. Black argillaceous lime mudstone separates some beds within an interval.

10.A.2.c. Depositional interpretation

The dominant lithology of black mudstone indicates deposition under anaerobic restricted circulation conditions (fig. 10.2). In the lower depositional unit, the argillaceous limestone records localized, shallow-water carbonate buildup with some transport of fossil debris. Crinoids and sponge spicules grow in relatively low-energy settings (Flugel, 1982; Wilson, 1975). Long, partially intact crinoid stems indicate deposition without major reworking. Elsewhere, the erosive bases and fining-upward character of thin, bioclastic packstone lenses suggest transportation by traction currents and deposition by waning storm-generated flows. Similar storm-generated deposits have been described by Kreisa and Bambach (1982). Interbedding of these bioclastic packstone lenses with black shale suggests transportation of the shelly material to sites of deposition along the side or base of a carbonate buildup. The varied fauna require normal-marine conditions, as opposed to the anaerobic conditions of the surrounding black shales. This suggests that the subenvironment, in which the organisms grew, formed above the surrounding anaerobic sea floor into shallow, oxygenated water.

Coarsening-upward sandstone intervals encased in black shale are consistent with marginal marine sandstone bodies such as progradational delta-front and strand-plain sequences (Elliott, 1986) and barrier-island sequences (Reinson, 1984). The limited lateral extent of these deposits suggests a point source of sediment input, perhaps a small river.

The black mudstone of the middle interval records a long period of monotonous deposition under anaerobic conditions. Implications of the black mudstone for depositional setting is discussed in section 10.C.

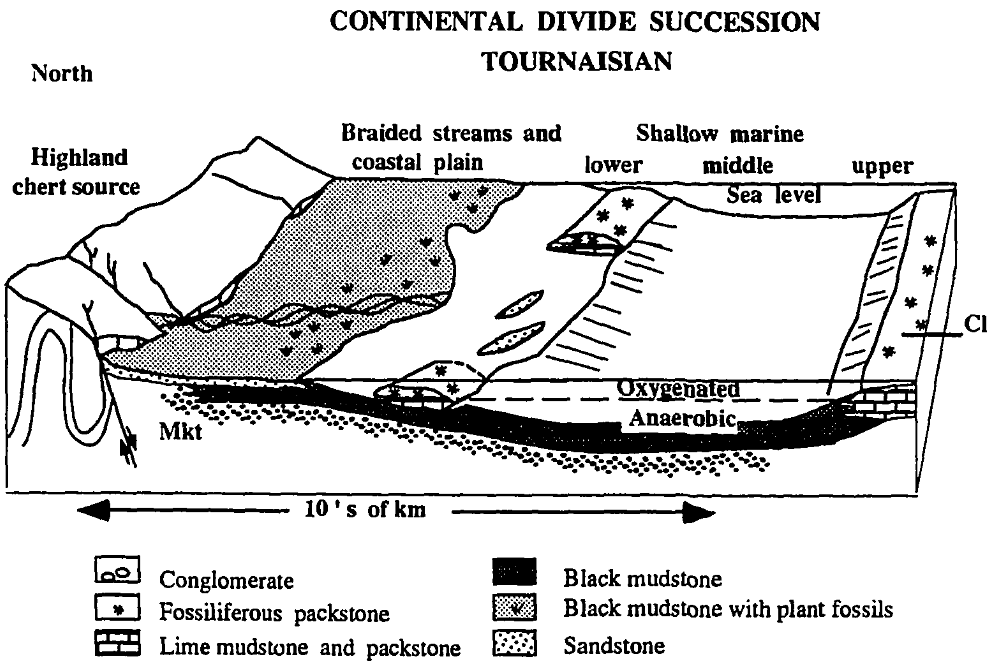


Figure 10.2. Schematic diagram illustrating depositional system of the lower, middle, and upper Kayak Shale. The Kayak Shale overlies and laterally intertongues with the Kekiktuk Conglomerate (Mkt). Platform carbonates of the Lisburne Group (Cl) prograde from the south.

The cyclic black mudstone and carbonate buildups in the upper unit of the Kayak Shale record initial unsuccessful efforts to establish the northward-onlapping Lisburne carbonate platform. The internal organization of these shallow-water carbonate buildups was not examined in detail. Farther north, where these cycles have been studied in more detail, they form shoaling-upward successions (LePain, 1993). The base of each cycle begins in relatively shallow water, below fair-weather wave base, and shoals to shallow subtidal depths (D. LePain, oral communication, 1992).

In the Aichilik pass thrust sheet, the Kayak Shale is unusual because it is interpreted to intertongue with the Kekiktuk Conglomerate. Abundant plant fossils and coal in black shale directly overlie the Kekiktuk Conglomerate intervals. Low, swampy coastal plains are a common setting for coal deposition (Galloway and Hobday, 1983). No marine fossils have been recovered from the intertonguing black shales. It is unclear if these black shales are in part the deposits of marine incursions or deposited entirely in a marginal, low-energy coastal-plain setting.

10.B. AGE

Regionally the age of the Kayak Shale is Early to early Late Mississippian (Tournaisian - Visean) (Brosge et al., 1988). Based on trilobites, conodonts, and plant spores, the age in the study area is middle or late Tournaisian to Visean. Limestones in the lower Kayak Shale contain late Tournaisian trilobites (G. Hahn, written communication, 1990). Conodonts in limestones in the lower Kayak Shale indicate an age of middle Tournaisian (prob. late Kinderhookian) and the upper Kayak as Visean (early Meramecian) (A.G. Harris, U.S. Geological Survey, written communication, 1991). Conodonts from the base of the overlying Lisburne Limestone indicate a Visean age (early Late Meramecian) (A.G. Harris, U.S. Geological Survey, written communications, 1989 - 1992). The shales yielded plant spores of Tournaisian to Visean age (J. Utting, Geological Survey of Canada, written communications, 1990 and 1991).

10.C. DEPOSITIONAL SETTING

The Kayak Shale is composed primarily of black shale deposited under anaerobic conditions in a marginal marine to marine setting. The fine grain size and black organic-rich mudstone indicate quiet-water deposition from suspension under anaerobic conditions beyond the influence of coarse-grained clastic deposition (Potter et al., 1980; Hosterman and Whitlow, 1983). Oxygen-deficient, organic-rich, quiet-water conditions are also indicated by the presence of *zoophycus* ichnofossils (Frey and Pemberton, 1984). Some workers suggest that during the Paleozoic, *zoophycus* ichnofossils were most abundant in shallow-water deposits (Frey and Pemberton, 1984). The color of black shale has been related to the amount of organic carbon present (Potter et al., 1980). Anaerobic bottom conditions can be caused by 1) poor water circulation resulting in density-stratified conditions that maintain oxygen-depleted conditions below a surface mixing zone, or 2) reduced circulation at the sediment-water interface due to abundant organic material (Jenkyns, 1986). The presence of a normal-marine fauna associated with the limestone beds in both the lower-third and upper-third of the Kayak succession indicate that normal-marine conditions occurred in the upper part of the water column. These relationships suggest a stratified water column with anaerobic bottom conditions below an oxygenated, surface mixing layer that allowed establishment of local carbonate buildups that were later drowned by rising sea level.

Typically, the lowermost deposits of the Kayak Shale are organic-rich mudstones with abundant plant fossils and coal. These basal deposits are the same whether deposited overlying the relatively planar upper surface of the Kekiktuk braid-channel system in the south, intertonguing with the Kekiktuk Conglomerate in the central area, or onlapping Ordovician chert paleohighs in the north. The association of plants and coal with black shales indicates a stagnant, swampy setting (Galloway and Hobday, 1983). Stratigraphic position below limestones containing a marine fauna indicates a coastal setting. These relationships suggest that initial Kayak deposition commenced in a low, swampy, coastal-plain setting. There is no indication of when the stagnant coastal swamps were flooded by marine waters. Limestones containing an open-marine fauna, 30 m above the base of the Kayak (Kongakut River thrust sheet), document the establishment of marine conditions by that time. The Tournaisian age of these lower Kayak limestones date initial Kayak transgression in the northeastern Brooks Range.

Intertonguing of multistory fluvial channel-fill deposits of the Kekiktuk Conglomerate within the lower Kayak Shale (Aichilik pass thrust sheet) suggests that the majority of coarse-grained clastic sediments were tied up in the fluvial system that crossed this coastal area. The overall upward-thinning and -fining of the Kekiktuk intervals suggest that nonmarine terrigenous clastic dispersal systems were retrograding in response to decreased amounts of sediment supplied to the system and/or relative sea-level rise.

To the south, in the Kongakut River thrust sheet, sandstone beds and limestone buildups are present at different places but in stratigraphically equivalent positions in the lower 100 m of the Kayak. These rocks record a marine coast with coeval carbonate and terrigenous clastic deposition. The limited lateral extent, 2 to 3 km, of the sandstone intervals suggests a local source for the sands, perhaps a river with limited sediment input into the marine basin. These deposits may be related to one of the upper Kekiktuk tongues of the Aichilik pass thrust sheet. Laterally equivalent limestone buildups contain a normal-marine fauna that requires localized areas with normal-marine conditions in oxygenated shallow-marine waters. Proximity to black shales requires a subenvironment above the anaerobic bottom conditions. These relationships may be a response to a sea-level low-stand which would promote limestone buildup within the photic zone and lower base level thereby increasing terrigenous clastic deposition into the marine setting.

The Kayak Shale records a major marine transgression along the southwestern margin of Arctic Alaska. This transgression may be in response to tectonic and thermal subsidence. However, it also coincides with an eustatic rise in the Tournaisian (Ross and Ross, 1987, cited in Savoy, 1992). Late Devonian to Tournaisian transgressive black shales are a widespread global phenomenon attributed by some workers to a flooding of shelf/epicontinental areas by an oxygen-depleted layer (for example, see Savoy, 1992). Flooding of the shelf by marine transgression with an oxygen-depleted lower layer would explain the close association of a normal-marine fauna in the limestone and black shales that indicate anaerobic bottom conditions. Alternatively, the anaerobic conditions could be a response to a lack of circulation caused by barriers internal to the basin (in structural lows caused by faulting), or by creation of a barrier for the Kayak basin by development of the extensive Lisburne carbonate platform (Armstrong, 1974) to the south. Additionally or alternatively, the abundant terrigenous organic material could have created anaerobic conditions at the sediment-water interface. All four of these conditions may have contributed to development of anaerobic bottom conditions during the Lower Mississippian.

11. PROVENANCE

The Middle Devonian to Mississippian terrigenous clastic succession is compositionally similar throughout the study area. Based on field observations and petrographic study, the clastic rocks are composed of quartz and chert pebble breccia and conglomerate, lithic arenite, and siliceous mudstone. Chert pebbles are subangular to subrounded and are dominantly varying shades of gray, although white and black are common. The purple-raspberry colored chert in the Kekiktuk Conglomerate appears to be a post-depositional weathering rind on light gray to white chert.

Qualitative study of thin-sections shows that the relative abundance of the individual grain types varies vertically and laterally, but not systematically. The framework grains include chert, argillaceous chert, cherty argillite, and vein quartz. Abundant radiolarian ghosts are present in the chert and argillaceous-chert grains. The chert category includes grains of equidimensional microcrystalline quartz with less than 5% impurities and crystal size less than 30 microns. This is an arbitrary division following the criteria of Folk (1980). The grain population shows a continuous gradation from pure chert to cherty argillite. The quartz species appears to be vein quartz. Vein-quartz grains commonly display a wide range of responses to strain, including deformation lamellae, undulose extinction, and sutured contacts.

The Ulungarat formation contains 60-100% chert, argillaceous chert, and cherty argillite. Vein quartz forms less than 40% of the framework grains. Terrigenous clasts in the Mangaqtaaq formation consist of chert and composite chert grains. The composite grains are evidence of recycled sand grains and suggest reworking of Ulungarat rocks.

The Kekiktuk Conglomerate tends to be more quartz-rich than the underlying succession, but locally chert is the dominant component.

Sixteen samples collected from the Ulungarat formation were point-counted. The sandstone samples have an average modal analysis of Q_m 10, F 0, L_t 90. Petrographic methods and data are reported in Appendix F. Detrital modal percentages are reported in Appendix G. Petrographic study and point counts of thin-sections allow the definition of petrofacies and inference of a petrographic profile of the source area. Sandstone provenance studies by Dickinson and Suczek (1979), Dickinson et al. (1982), and Dickinson (1985) have shown that detrital modes for sandstones plot in fields characteristic of derivation from different tectonic realms. Calculated detrital modes for Ulungarat formation sandstones plot in a distinct group on a ternary diagram. This evidence indicates that the provenance for the Ulungarat formation was a recycled orogenic belt with a major component of marine chert. The composition does not vary significantly within the overlying Mangaqtaaq formation and Kekiktuk Conglomerate suggesting a common provenance.

The probable source terrain for the clastic rocks in the study area is the Romanzof chert, which in the north was apparently exposed to erosion from Middle Devonian to Early Mississippian time. The Romanzof chert contains bedded to massive, gray, black, and white radiolarian chert with intercalated argillite that is lithologically identical to clasts in the Devonian to Mississippian succession. Quartz veins within the Romanzof chert commonly contain strain lamellae similar to those present in quartz clasts within the Middle Devonian to Mississippian succession. This is consistent with a local source for the quartz as well as for the chert.

12. LOCAL DEPOSITIONAL GEOMETRY AND IMPLICATIONS OF UNCONFORMITIES

12.A. EVIDENCE FOR DEPOSITION ACROSS A BASIN MARGIN

North to south changes in the character and thickness of the stratigraphic section suggest an abrupt Middle Devonian to Early Mississippian basin margin. Several significant relationships support the interpretation that the west fork valley succession records a Middle Devonian to Mississippian basin margin to the north and the continental divide succession records deposition in a basin south of this margin. The terrigenous clastic succession deposited between the underlying complexly deformed Romanzof cherts and the overlying carbonates of the Lisburne Group forms a southward-thickening clastic wedge that abruptly thickens from about 100 m in the west fork valley succession in the north to about 1000 m in the continental divide succession (fig. 5.3). The increased thickness is partially due to the presence of two formations at the base of the continental divide succession that are absent to the north, the Ulungarat and Mangaqtaaq formations, but also to the southward increase in thickness of the Kekiktuk Conglomerate and Kayak Shale at the top of the thrust sheets. Thus, the depositional record to the south ranges to older ages than to the north, and equivalent stratigraphic units thicken southward. In addition, equivalent stratigraphic units are more distal to the south and the depositional record indicates southward progradation of depositional systems prior to Early Mississippian transgression. The marine deposits at the base of the continental divide succession and the Early Mississippian marine transgression from the south both indicate the presence of an ocean basin to the south. Collectively, these characteristics indicate deposition from a sediment source area to the north into a major basin to the south.

The similarity in composition of clasts throughout the terrigenous clastic succession with the Romanzof chert also suggests northward derivation from a nearby source. If so, the Romanzof chert would have been exposed to erosion in the north from Middle Devonian to Early Mississippian time, which is consistent with the unconformable deposition of the Kekiktuk Conglomerate on pre-Middle Devonian rocks to the north. Deposition of only a relatively thin and late veneer of Kekiktuk Conglomerate over a regionally extensive area to the north suggests that this region was a regional erosional high for a substantial period of time (LePain, 1993). This high did not become a site of deposition until progressive northward onlap of the erosion surface began during Early Mississippian transgression.

Stratigraphic thickness and facies change abruptly between the west fork valley and continental divide successions. Several unconformities merge northward in the same area. In addition, the stratigraphic record indicates nearby topographic relief to the north at the time of deposition. These relationships suggest that the boundary between the west fork valley and continental divide successions coincided with a relatively abrupt basin margin.

12.B. IMPLICATIONS OF UNCONFORMITIES

A composite erosion surface above highly deformed pre-Middle Devonian rocks is observed or interpreted to have been depositionally overlain by much less deformed rocks of different ages across the area. To the south, Middle Devonian rocks of the Ulungarat formation are interpreted to have been deposited on this erosion surface, which indicates that the complex deformation of the underlying rocks was pre-Middle Devonian and marks a major change in tectonic setting. In the same area, unconformities within the

Middle Devonian to Mississippian clastic wedge display only slight angular discordance and represent less profound tectonic changes. However, the sub-Kekiktuk unconformity truncates the sub-Ulungarat unconformity to the north. Thus, Kekiktuk Conglomerate unconformably overlies the erosion surface above pre-Middle Devonian rocks to the north, a relationship that is present throughout most of the northeastern Brooks Range and North Slope.

12.B.1. Erosion Surface Above The Romanzof Chert

To the south, the Ulungarat formation lacks polyphase contractional structures characteristic of the Romanzof chert and a major angular unconformity is interpreted to have originally separated the two units. To the north, the Kekiktuk Conglomerate directly overlies the Romanzof chert on an angular unconformity. The Romanzof chert records contractional structures of the last mid-Paleozoic orogeny to have affected the area, whereas unconformably overlying rocks post-date the Paleozoic orogeny and record only Cretaceous(?) to Tertiary contractional structures of the Brookian orogeny. The age of the latest mid-Paleozoic contractional deformation to have affected the area is bracketed by the Ordovician age of the Romanzof chert and the Middle Devonian age of the Ulungarat formation.

To the north, throughout most of the northeastern Brooks Range and North Slope, Middle and Upper Devonian rocks are absent and the Lower Mississippian Kekiktuk Conglomerate unconformably overlies pre-Middle Devonian rocks (Grantz et al., 1990; Reiser et al., 1980). Rocks as young as Early Devonian unconformably underlie the Kekiktuk Conglomerate in several places throughout the region. In the northern Yukon Territory, 100 km to the northeast of the study area, complexly deformed rocks as young as Emsian (late Early Devonian) underlie the sub-Kekiktuk unconformity (Norris, 1986). The late- to post-tectonic Okpilak batholith, 35 km to the north of the study area, has yielded a U/Pb crystallization age on zircon of 380 +/- 10 Ma (late Early Devonian, Harland et al., 1982) and is unconformably overlain by Kekiktuk Conglomerate (Dillon et al., 1987b). In the Shublik and Sadlerochit Mountains, at the northern front of the northeastern Brooks Range, thick lower Paleozoic carbonate strata as young as Emsian are unconformably overlain by Lower Mississippian rocks (Blodgett et al., 1991).

Because of the great regional extent of the sub-Kekiktuk unconformity, it has commonly been assumed that the latest mid-Paleozoic contractional deformation was during Late Devonian to Early Mississippian time (Grantz et al, 1990). However, within the study area, mid-Paleozoic contractional structures are absent in rocks as old as Eifelian (early Middle Devonian). If deformation is assumed to have been synchronous throughout the northeastern Brooks Range, then the age of the latest mid-Paleozoic contractional deformation is tightly constrained to the boundary between the Early and Middle Devonian by the Emsian age of the youngest deformed rocks and the Eifelian age of the oldest undeformed rocks.

Middle Devonian and younger rocks are absent beneath the Kekiktuk Conglomerate to the north, so there is a greater gap in the record than to the south. Middle Devonian and younger rocks could have been deposited and removed by erosion over at least part of the region before deposition of the Kekiktuk. Alternatively, the region may have been a site of continuous erosion, with no Middle Devonian and younger rocks ever having been deposited before Kekiktuk deposition. The latter interpretation is more likely for at least part of the region because clasts in Middle

Devonian and younger deposits beneath the Kekiktuk in the study area were derived by erosion from local sources to the north.

12.B.2. Unconformities Within The Middle Devonian To Mississippian Rocks

In addition to the inferred high-angle discordance at the base of the Ulungarat, observed low-angle discordances are present at the bases of both the Mangaqtaaq formation and the Kekiktuk Conglomerate within the continental divide succession (fig. 5.3). These are interpreted to be unconformities that formed between successive episodes of southward tilting. The sub-Mangaqtaaq and sub-Ulungarat unconformities are successively truncated northward beneath the sub-Kekiktuk unconformity. Such low-angle discordance can be a record of concurrent deposition and deformation. The abrupt southward increase in thickness of the stratigraphic section records an abrupt increase in accommodation, suggesting subsidence to the south. Derivation of the terrigenous clastic detritus that composes the section from local underlying units requires sufficient local relief to expose the older units to erosion. Local evidence for possible syndepositional high-angle faulting suggests faulting as the mechanism for creating this relief.

Locally derived coarse-grained deposits and low-angle unconformities suggest episodic local tectonic activity throughout deposition of the continental divide succession. Erosional unconformities within the succession may also be a response to relative sea-level change due to other causes, such as regional tectonics or eustacy. It is not possible to determine the influence of eustatic sea-level change on the sedimentary deposits. Johnson and Sandberg (1988) report an overall Devonian eustatic rise followed by a Late Devonian eustatic fall. Progradation of a coarse-grained alluvial fan during a time of overall eustatic rise suggests tectonic activity as the dominant control on Devonian deposition in the area. The low-angle erosional unconformities may, in part, be related to Late Devonian regression due to eustatic sea-level drop. Additionally or alternatively, the erosional unconformities could be the result of local tectonic causes, such as erosion of the relatively high areas of tilted fault blocks. The rapid transgression of the Kayak Shale across northern Alaska is a response to increased accommodation and coincides with the eustatic rise reported for the Early Tournaisian (Ross and Ross, 1985).

13. DEPOSITIONAL EVOLUTION AND CONTROLS

13.A. EIFELIAN (EARLY MIDDLE DEVONIAN) TO EARLIEST MISSISSIPPIAN DEPOSITION

To the south, in the continental divide succession, deposition above the inferred sub-Ulungarat unconformity began during the Eifelian (Early Middle Devonian) (fig. 5.3). Shallow-marine delta-plain deposits of the lower part of the Ulungarat formation were progradationally succeeded by alluvial-fan deposits of the upper part of the formation and unconformably overlain by lacustrine or restricted shallow-marine deposits of the Mangaqtaaq formation. These deposits record the progradation of a terrigenous clastic system, followed by erosion and local deposition in restricted basins. To the north, in the west fork valley succession, the lack of coeval deposits is interpreted to reflect erosion of a paleotopographic high which formed the basin margin.

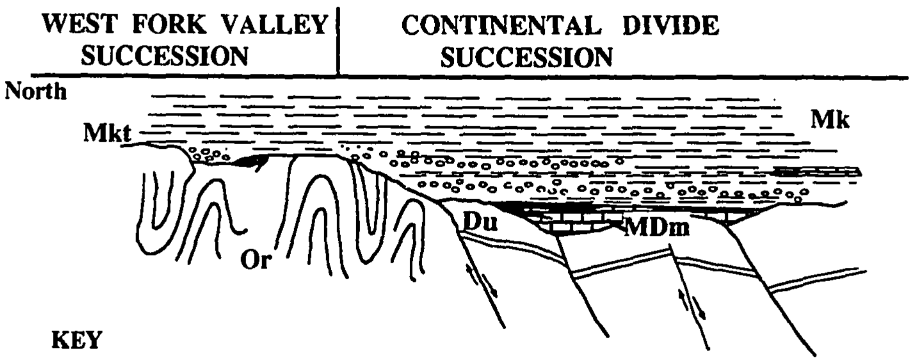
The Devonian succession was deposited in a rapidly subsiding basin bounded to the north by a basin-margin highland. The composition of the terrigenous clastic deposits and their southward transport direction indicate that they were derived from local sources in the Romanzof chert, to the north. The age of the deposits coincides with an erosional gap in the record in the northern source area. The continued derivation of detritus from the Romanzof chert indicates that sufficient topographic relief existed to maintain the unit as an erosional source from Middle Devonian to earliest Mississippian time.

Progradational stacking of increasingly coarse-grained deposits, erosion within the succession, and low-angle unconformities suggest an active tectonic regime. Erosion at the top of the Ulungarat formation is indicated by lateral truncation of its nonmarine members and by the presence of clasts derived from the Ulungarat formation within the overlying Mangaqtaaq formation. The low-angle discordance between these formations and of both with the overlying Kekiktuk Conglomerate suggests that tilting of the clastic wedge caused local relief and formation of local erosional highs. An active tectonic setting is also supported by the offset on probable pre-Kekiktuk high-angle faults of the upper erosional surface of the Ulungarat formation where it is overlain by the Mangaqtaaq formation.

The localized lacustrine or restricted marine deposits of the Mangaqtaaq formation formed in a hydrologically closed basin, suggesting that physical barriers created topographic lows. Deposition of the formation over the maximum preserved thickness of the Ulungarat formation indicates local subsidence of the Ulungarat formation beneath the basin while other Ulungarat rocks remained topographically high and served as a source of detritus for the Mangaqtaaq formation. Together, these relationships suggest a structurally restricted basin created by tilting of the Ulungarat formation.

13.B. TOURNAISIAN (EARLY MISSISSIPPIAN) DEPOSITION

Deposition of the Kekiktuk Conglomerate began in the continental divide succession to the south with a coarse-grained, braided fluvial system deposited with slight angular discordance over the Ulungarat and Mangaqtaaq formations (fig. 9.1 and 13.1). This initial Kekiktuk fluvial system marks renewed deposition over the erosional unconformity at the top of the Ulungarat and Mangaqtaaq formations. Composition and transport direction indicate that the probable source of these clastic rocks continued to be the Romanzof chert along the basin margin to the north. Renewed coarse-grained



KEY

Black mudstone	Mk	Kayak Shale
Conglomerate and sandstone	Mkt	Kekiktuk Conglomerate
Black mudstone with plant fossils	MDm	Mangaqtaaq Formation
Limestone	Du	Ulungarat Formation
Deformed chert and argillite	Or	Romanzof chert

Figure 13.1. Schematic diagram of Mississippian depositional system showing deposition of Mangaqtaaq Formation within localized restricted setting created by down-dropped fault blocks. Mangaqtaaq Formation is overlain by retrograding fluvial system of the Kekiktuk Conglomerate and marine transgression of the Kayak Shale. Interpretation as extensional tectonic setting discussed in chapter 14.

terrigenous clastic deposition may have been a response to increased accommodation created by the rise in relative sea level recorded by the overlying Kayak transgression.

13.C. LATEST TOURNAISIAN TO VISEAN (EARLY TO MIDDLE MISSISSIPPIAN) DEPOSITION

To the south, in the continental divide succession, coastal-plain to marine shales of the Kayak transgression overlie and intertongue with retrogradational deposits of the Kekiktuk Conglomerate, recording coastal retreat and drowning of a low-energy paleoshoreline (fig. 10.2) Apparent intertonguing of Kekiktuk Conglomerate and Kayak Shale may be the combined record of subsidence and periodic influxes of clastic detritus that could be related to eustatic lowstands, episodic uplift caused by reactivation of faults along the basin margin, and/or climatic fluctuations. Additionally or alternatively, coarse-grained clastic detritus and the black shales may have both been deposited within the coastal-plain fluvial system, representing channel and interchannel deposits respectively. Deposits of the retrograding fluvial system thin and fine upward and to the north in the west fork valley succession.

To the north, along the basin margin, the west fork valley succession includes thin, laterally discontinuous, locally derived debris flow, colluvial, and fluvial deposits of the Kekiktuk Conglomerate and black coastal-plain and marine muds of the Kayak Shale (fig. 9.3). Paleotopography along the underlying unconformity surface was a primary control on Kekiktuk deposition. The relief may have been in part erosional, but local evidence suggests that possible syndepositional high-angle faults influenced Kekiktuk deposition. The interfingering of Kekiktuk Conglomerate with black shales containing plant fossils and coal suggests a low-energy, wet, coastal plain that was eventually transgressed by Kayak marine shales. Stratigraphic position suggests that this thin stratigraphic succession may be the same age as the youngest tongue of Kekiktuk deposits to the south. This succession onlaps the erosion surface that was the probable source of the thick, coarse-grained terrigenous clastic deposits to the south. The Kayak Shale records the initial deposition of a major marine transgression.

14. REGIONAL STRATIGRAPHIC CORRELATION AND PALEOGEOGRAPHY

The Middle Devonian to Early Mississippian record of terrigenous clastic deposition in the study area provides important insights into the tectonic and depositional evolution of the region and the depositional relationships between the allochthonous Endicott Group to the south and the parautochthonous to autochthonous Endicott Group to the north. North-vergent Brookian folding and thrusting has disrupted the original spatial and depositional relationships among the various parts of the Endicott Group. However, a genetic relationship between the continental divide succession and the allochthonous Endicott Group is indicated by close similarities in lithology, provenance, depositional organization, sediment transport direction, and stratigraphic position (fig. 14.1). Both record south-to-southwest prograding, coarse-grained fluvial depositional systems that were succeeded by the transgressive Kayak Shale. Both the allochthonous succession (Nilsen and Moore, 1984; Anderson, 1987) and the continental divide succession have a chert-rich provenance. Clast composition and sediment transport direction suggest that the source area for both included the pre-Middle Devonian chert now exposed in the northeastern Brooks Range. The continental divide succession records fluvial deposition beginning earlier than in the allochthonous Endicott Group, and lacks definitive evidence for deposition during Late Devonian time, when most of the allochthonous Endicott Group was deposited. However, these apparent discrepancies can be explained by progradation and across-strike variations in depositional geometry, as discussed below.

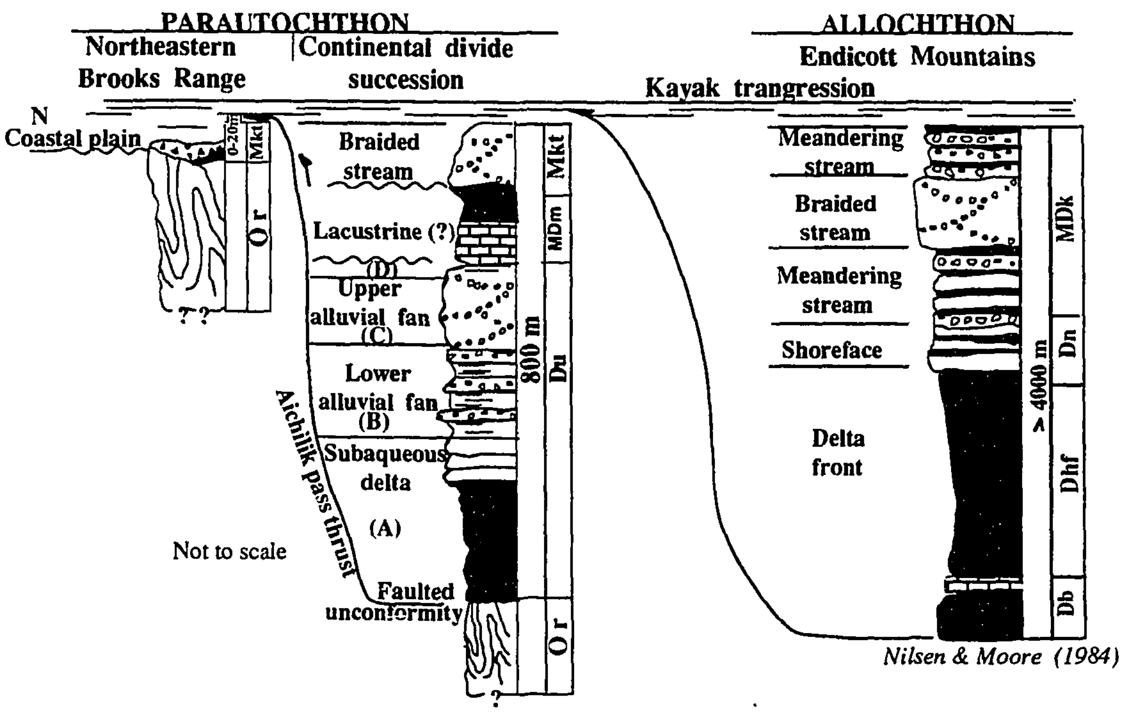


Figure 14.1. Generalized stratigraphic columns showing depositional setting for the three successions of Middle Devonian to Mississippian terrigenous clastic rocks. Allochthonous succession: Beaucoup Formation (Db), Hunt Fork Shale (Dhf), Noatak Sandstone (Dn), and Kanayut Conglomerate (MDk). Parautochthonous continental divide succession: Ulungarat formation.(Du), Mangaqtaaq formation (MDm), and Kekiktuk Conglomerate (Mkt). Parautochthonous northeastern Brooks Range succession: Kekiktuk Conglomerate (Mkt) and Romanzof chert (Or).

The west fork valley succession marks the southern edge of the parautochthonous to autochthonous Endicott Group. Throughout the northeastern Brooks Range and North Slope subsurface, relatively thin Kekiktuk Conglomerate overlies pre-Middle Devonian rocks with profound angular unconformity, and is in turn overlain by the transgressive Kayak Shale. Thicker terrigenous clastic sections, some including Devonian rocks, are present only in local fault-bounded basins in the North Slope subsurface.

Although they are very different, the continental divide and west fork valley successions clearly are genetically related. They are separated by a thrust fault that, in at least one place, has a displacement of no more than 1.5 km. Clasts in both successions were derived from the Romanzof chert. This unit unconformably underlies the west fork valley succession and is interpreted also to have unconformably underlain the continental divide succession, although that unconformity has been modified by a thrust fault in the study area. Both successions include the Keikiktuk Conglomerate and the Kayak Shale, although they are thinner in the west fork valley succession which lacks the Middle Devonian and younger depositional record present below the sub-Kekiktuk unconformity in the continental divide succession. These relationships are best interpreted to represent the once laterally continuous record of deposition across a basin margin, now disrupted by north-vergent thrust faulting. This relationship between the continental divide and west fork valley successions provides a link between the allochthonous Endicott Group and the parautochthonous to autochthonous Endicott Group, if the continental divide succession is assumed to be genetically related to the allochthonous Endicott Group.

Similarly, the Middle Devonian to Early Mississippian record of terrigenous clastic deposition in the study area provides an important link between the histories of the allochthonous Endicott Group to the south and the parautochthonous to autochthonous

Endicott Group to the north, allowing a coherent reconstruction of regional tectonic and depositional evolution for the time period (fig. 14.2). A major change in tectonic setting beginning in Middle Devonian time is indicated by the contrast in degree and character of deformation across the sub-Ulungarat unconformity. The earliest record of deposition reflecting this change in tectonic setting includes the Middle to Upper (?) Devonian rocks of the continental divide succession and the Middle Devonian graben-fill deposits documented in the Topagoruk #1 well. The basis for correlation of these two successions is the similarity in lithology, age, and interpreted stratigraphic position unconformably overlying complexly deformed older rocks.

Regional progradation of the Middle to Upper(?) Devonian clastic depositional system of the continental divide succession is represented by the allochthonous Endicott Group to the south and southwest (fig. 14.2). In contrast with the Middle Devonian marine to nonmarine transition in the continental divide succession, this transition is Late Devonian in the allochthonous Endicott Group, indicating progradation over a considerable period of time. Definitive evidence is lacking to confirm deposition in the continental divide succession during Late Devonian time, when most deposition of the allochthonous Endicott Group took place. However, the available age constraints do not preclude the presence of Upper Devonian deposits in the continental divide succession, although they would be thinner than in the allochthonous Endicott Group. Similarly, the evidence is not currently available to confirm that the continental divide succession and allochthonous Endicott Group were parts of a single geographically and temporally continuous progradational depositional system. Deposition of the continental divide succession was interrupted by erosion prior to deposition of the Kekiktuk Conglomerate and could have been isolated from the depositional basin of the allochthonous Endicott

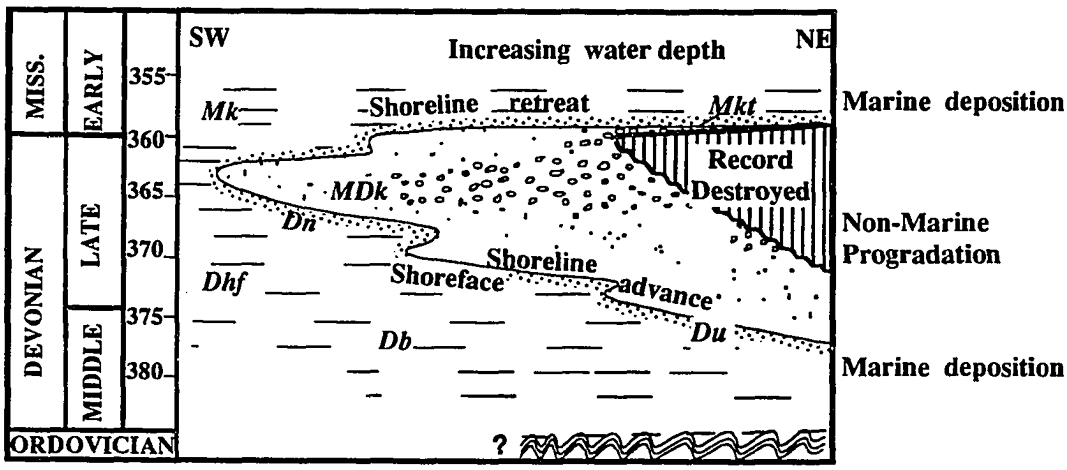


Figure 14.2. Schematic cross-section of Middle Devonian to Early Mississippian deposition showing progradation and transgression of the terrigenous clastic wedge. Note the vertical axisis time. Ulungarat formation (Du), Beaucoup formation (Db), Hunt Fork Shale (Dhf), Noatak Sandstone (Dn), Kanayut Conglomerate (MDk), Kekiktuk Conglomerate (Mkt), and Kayak Shale (Mk).

Group. However, the similarities in provenance, transport direction, depositional character and setting, and uppermost stratigraphy all argue for a close genetic relationship even if deposition was not geographically and temporally continuous between the two successions.

In the northeastern Brooks Range and most of the North Slope subsurface, the Kekiktuk Conglomerate unconformably overlies complexly deformed pre-Middle Devonian rocks and there is no record of Middle to Upper Devonian deposition. In the continental divide succession, Kekiktuk Conglomerate unconformably overlies Middle Devonian to lowermost Mississippian (?) rocks of the Ulungarat and Mangaqtaaq formations on a low-angle unconformity. A conformable nonmarine succession spans the Devonian-Mississippian boundary in the allochthonous Endicott Group, but the Kekiktuk Conglomerate has not been identified as a separate unit. Thus, progressively more time is represented by the record missing beneath the sub-Kekiktuk unconformity to the north, probably reflecting a progressively longer period of continuous erosion to the north. In all three successions, coarse-grained fluvial deposition was gradationally succeeded by fine-grained marine deposition in the northward-transgressive Kayak Shale.

No record of Middle to Upper Devonian deposition exists beneath the sub-Kekiktuk unconformity in the northeastern Brooks Range and most of the North Slope subsurface. Clasts in the continental divide succession and the allochthonous Endicott Group apparently were derived at least in part from sources now exposed in the northeastern Brooks Range. These observations suggest that the region was a long-standing regional topographic high and site of erosion. Such an extensive high probably was tectonically controlled. Regional south- to southwestward progradation and thickening of a Middle Devonian to Early Mississippian clastic wedge away from this high and northward merging of unconformities toward the high indicate increased accommodation to the south, probably reflecting tectonic subsidence. The regional high to the north is separated from the regional low to the south by a sharp basin margin reflected by the abrupt changes in thickness and stratigraphy between the west fork valley and continental divide successions. Accommodation over a much more extensive area, although of lesser magnitude, is recorded by deposition of the generally thin veneer of Kekiktuk Conglomerate to the north, succeeded by marine deposits of the Kayak Shale throughout the region. This resulted in drowning of the highland source terrane to the north and a consequent abrupt shift to very fine-grained clastic deposition, eventually superseded by carbonate deposition.

15. TECTONIC INTERPRETATION AND REGIONAL IMPLICATIONS

The Devonian to Mississippian terrigenous clastic succession of the study area displays characteristics typical of deposition in a rift to passive continental margin setting. Regional stratigraphic relationships fit this interpretation as well, with the study area occupying a position across the rift-basin margin. The stratigraphic succession in a rift to passive continental margin setting is typically characterized by a basal rift-onset unconformity, syn-rift deposits, a post-rift unconformity, and progressive onlap of the basin margin by post-rift deposits (fig. 15.1) (Braun and Beaumont, 1989; White and McKenzie, 1988; Steckler and Watts, 1982). The rift-onset unconformity marks a change from the tectonic setting recorded in underlying rocks to extension resulting in rapid tectonically controlled subsidence. The down-dropped fault-blocks create half-grabens that fill with thick syn-rift deposits. Unconformities are common within syn-rift deposits and record continued faulting and tilting (Hutchinson and Klitgord, 1988; Smale et al., 1988). The post-rift unconformity is interpreted to mark continental breakup to form a passive continental margin and the end of the tectonically controlled stage of subsidence (Steckler et al., 1988). The unconformity develops in response to uplift of the tectonic hinge-zone and the area landward of it (Hutchinson and Klitgord, 1988; Braun and Beaumont, 1989). The tectonic hinge-zone forms the boundary between extensionally thinned crust and unthinned crust. The post-rift unconformity separates tilted syn-rift deposits and older basin-flank strata from younger strata deposited during relative sea-level rise. The rise in sea level is in response to slow, regional subsidence that extends farther landward than during earlier extensional subsidence. This subsidence is

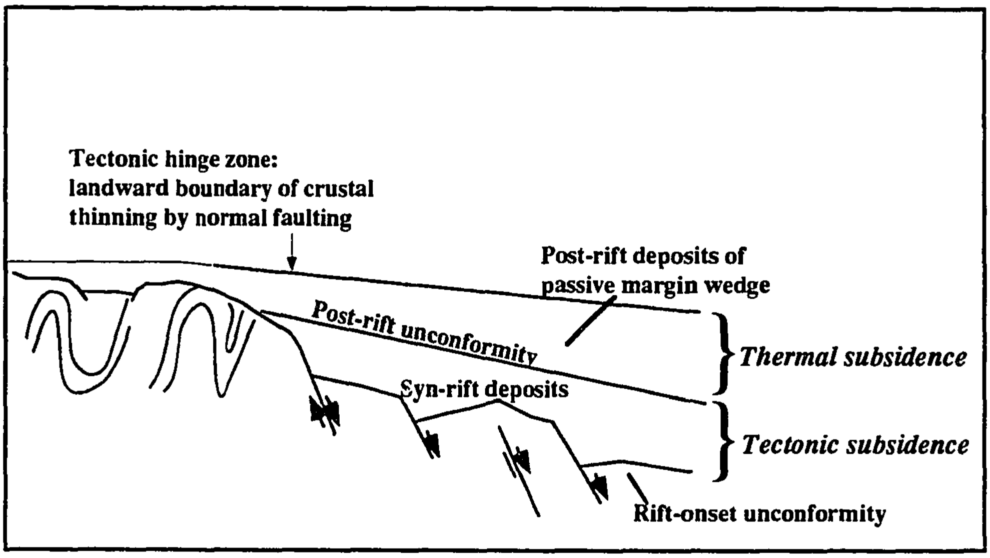


Figure 15.1. Diagram of the tectonic and stratigraphic elements across a rift-basin margin.

controlled by thermal contraction of the crust and sediment loading (Steckler et al., 1988). The stratigraphic succession that overlies the post-rift unconformity is characterized by progressive onlap of the basin margin and by development of a basinward-thickening wedge.

In northern Alaska, regional stratigraphic evidence indicates the onset of rifting sometime in the Devonian, followed by prolonged deposition on a passive continental margin (See chapter 2) (Grantz and May, 1988; Grantz et al., 1990; Moore et al., 1992). Middle Devonian to Mississippian clastic deposits in the study area record the major tectonic transition from previous contractional deformation to rifting and passive-margin subsidence (fig. 15.2). The unconformity at the base of the continental divide succession marks a change from polycontractionally deformed rocks below to rocks that were only slightly tilted before Brookian deformation above, and is interpreted to be the rift-onset unconformity. The stratigraphic succession overlying the unconformity is characterized by 1) abrupt facies changes, 2) abrupt southward thickening associated with local evidence of active tectonism, 3) multiple unconformities merging northward toward the basin margin, 4) locally derived clastic deposits, and 5) closely associated shallow marine, nonmarine, lacustrine(?), and to the west volcaniclastic deposits (Anderson et al., 1993). These characteristics are consistent with syn-rift deposition in an extensional setting. Alternatively, these characteristics could be interpreted to reflect relatively minor late-stage fold and thrust deformation. However, there is no direct evidence of contractional structures of this age, and the regional evidence is much more consistent with an extensional setting.

Low-angle discordances such as those within the continental divide succession are common in syn-rift deposits seaward of a passive-margin hinge zone (Hutchinson and

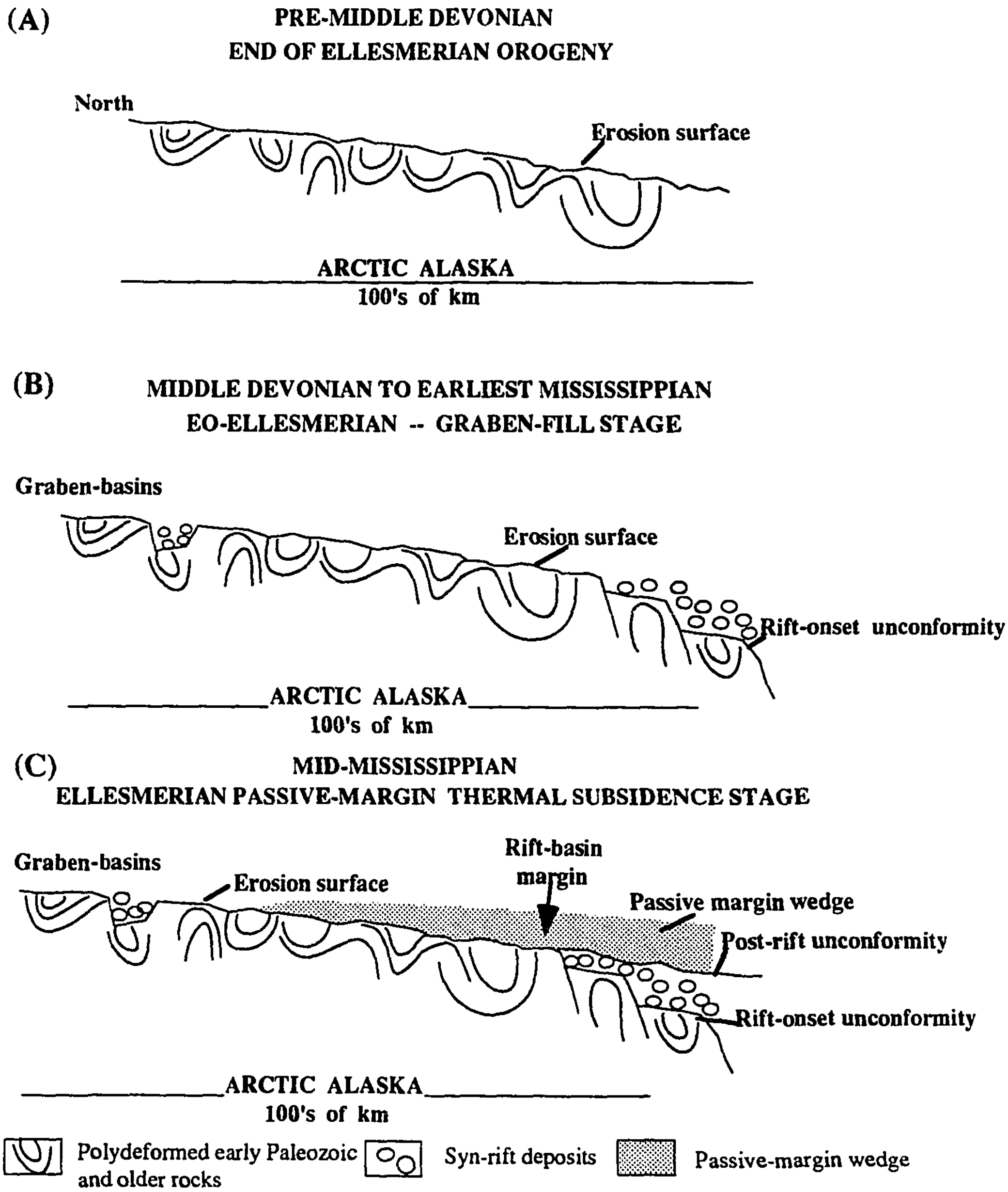


Figure 15.2. Schematic diagram of pre-Middle Devonian to Mississippian tectonic evolution of Arctic Alaska. (A) Erosion beveled the Arctic platform truncating strata deformed by the Ellesmerian orogeny. (B) Rift stage of the Ellesmerian passive margin development forms grabens and half-grabens on the Arctic platform. Notice that much of the surface continued as an erosional high. (C) In the south, uplift of the rift-basin margin was followed by development of the post-rift unconformity and the beginning of the thermal subsidence stage. Deposits of the passive margin wedge onlap the Arctic platform to the north. Notice that topographically high parts of the Arctic platform continued to be surfaces of erosion until onlapped by the passive margin wedge.

Klitgord, 1988; Smale et al., 1988). Such low-angle discordance may result from tilting of fault blocks, with erosion occurring along their uplifted edges, or thermal uplift of a basin margin, causing basinward tilting of the entire section and erosion of uplifted areas. High-angle faults, multiple unconformities, and merging of those unconformities toward the basin margin are consistent with an extensional tectonic regime (Hutchinson and Klitgord, 1988; Braun and Beaumont, 1989).

In the study area, the sub-Kekiktuk unconformity is interpreted to be the post-rift unconformity because it is overlain by deposits reflecting slower, but more widespread subsidence that extended landward of the previous basin margin. The Kekiktuk Conglomerate and Kayak Shale onlap progressively older rocks to the north and record a regional marine transgression, supporting an interpretation that their deposition reflects thermal subsidence.

This interpretation of the tectonic setting of Middle Devonian to Mississippian terrigenous clastic deposition in the study area fits well with regional stratigraphic relationships, with differences in stratigraphic successions throughout the region reflecting different positions across a rift and later passive continental margin.

A major regional erosion surface in northern Alaska truncates underlying highly deformed pre-Middle Devonian rocks and defines the base of the Ellesmerian Sequence (fig. 15.2.A). This surface is overlain by rocks ranging from Middle Devonian to Mississippian age in different places. The oldest well-dated rocks interpreted to be deposited on this erosion surface are the Middle Devonian rocks of the study area. This relationship constrains the latest mid-Paleozoic contractional deformation to pre-Middle Devonian time and is the most likely candidate for the rift-onset unconformity in the region. The erosion surface was cut by normal faults to form local basins in what is now the North Slope subsurface (fig. 15.2.B). The Middle Devonian to Lower Mississippian syn-rift deposits filling these basins have been assigned to the Eo-Ellesmerian stage (Grantz and May, 1988). The syn-rift deposits between the sub-Ulungarat and sub-Kekiktuk unconformities in the continental divide succession are also here assigned to the Eo-Ellesmerian stage.

Continuous terrigenous clastic deposition from Middle Devonian through Early Mississippian time is recorded in the allochthonous Beaucoup Formation and Endicott Group in the north-central Brooks Range. The rapid progradational deposition and regional setting of these rocks are consistent with their deposition in a tectonically subsiding basin. Deposition during much of this time may also be recorded in the rocks of the continental divide succession, but a record representing an unknown amount of time is missing beneath the sub-Mangaqtaaq and sub-Kekiktuk unconformities. In contrast, in the west fork valley succession and throughout the northeastern Brooks Range and most of the North Slope subsurface, pre-Middle Devonian rocks are directly overlain by the Lower Mississippian Kekiktuk Conglomerate. Thus, this entire region differs from the region to the south in that it was an erosional high prior to Kekiktuk deposition. The abrupt changes in stratigraphy between the continental divide and west fork valley successions are interpreted to reflect a sharp basin margin. The regional contrast between probable syn-rift deposits to the south of this inferred basin margin and a regional erosion surface to the north suggest that it was the northern boundary of a region of extensional subsidence, and hence may represent the regional tectonic hinge zone. The comparative thinness of the Kekiktuk Conglomerate throughout the northeastern Brooks Range suggests post-rift deposition landward of the tectonic hinge zone (LePain, 1993).

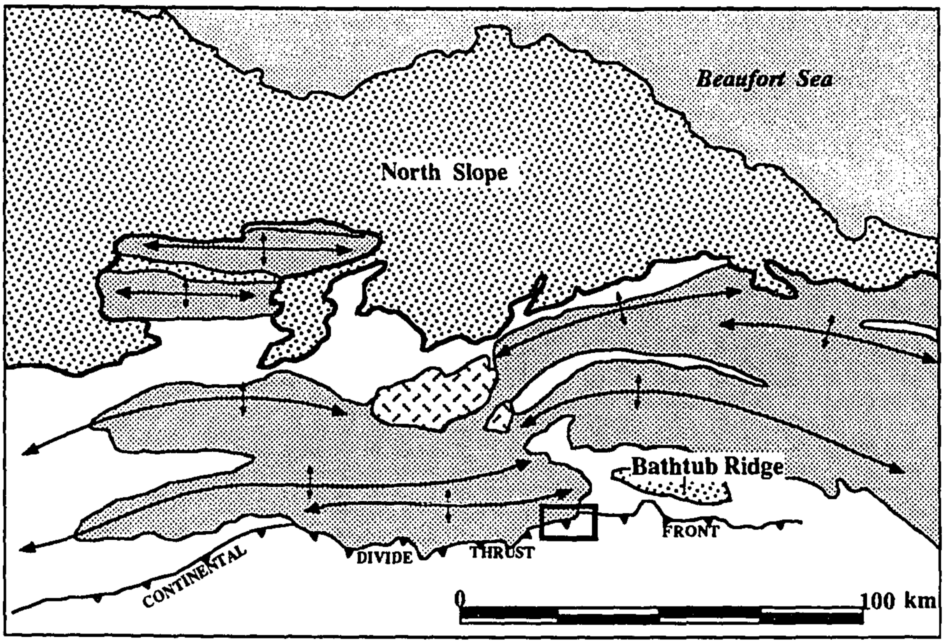
The Lower Mississippian Kekiktuk Conglomerate marks the onset of deposition extending across the rift-basin margin (fig. 15.2.C). Kekiktuk rests unconformably on pre-rift rocks throughout the northeastern Brooks Range and most of the North Slope subsurface and on Middle Devonian and younger syn-rift rocks in the continental divide succession. In contrast, Kekiktuk-equivalent rocks are part of a conformable succession in the allochthonous Endicott Group to the south. Onlapping deposition of the marine Kayak Shale throughout the entire region marks a northward regional transgression. Deposition of these units represents slower subsidence extending regionally to the north of the former basin margin, which suggests a cessation of extensional subsidence to the south and onset of regional thermal subsidence. In this case, the sub-Kekiktuk unconformity would represent the post-rift unconformity. Although normal faulting continued into the Early Mississippian in the North Slope subsurface, it was restricted to isolated basins. Deposition of a regionally southward-thickening and -deepening wedge, interpreted as a passive-margin wedge, continued at least until onset of Brookian deformation in Late Jurassic time.

16. VARIATIONS IN STRUCTURAL GEOMETRY ACROSS THE CONTINENTAL DIVIDE THRUST FRONT, NORTHEASTERN BROOKS RANGE, ALASKA

16.A. INTRODUCTION

In the eastern Brooks Range, a major structural boundary, the "continental divide thrust front," separates two distinct structural provinces (fig. 16.1) (Wallace et al., 1988). To the south, the main east-west axis of the Brooks Range is an area of complex closely spaced north-vergent folds and imbricate thrust faults formed mainly during the Late Jurassic to Cretaceous part of the Brooks Range orogeny. The younger northeastern salient of the range is distinguished by a different structural style characterized by major east-west trending, doubly plunging anticlinoria cored by lower Paleozoic rocks and overlain by detachment folds formed in Mississippian and younger rocks. The anticlinoria are interpreted to be the surface expression of horses in a regional duplex (Wallace and Hanks, 1990). The Kayak Shale horizon, near the base of the Mississippian rocks, forms a major detachment horizon and is interpreted to be the roof thrust of the regional duplex. For a more detailed discussion of these relationships see Wallace and Hanks (1990).

In the northeastern Brooks Range, the Paleozoic stratigraphic succession consists of two stratigraphic sequences separated by a major regional erosion surface. This surface marks a major change in tectonic setting in northern Alaska. The lower stratigraphic sequence is a poorly understood, lithologically heterogeneous assemblage of pre-Middle Devonian polydeformed, low-grade metasedimentary and metavolcanic rocks (Grantz et al., 1990). These rocks show multiple generations of folds, thrusts, and .



Regional anticlinoria cored by pre-Middle Devonian rocks
Devonian Okpilak Batholith and Jago Stock
Middle Devonian to Lower Cretaceous rocks, Ellesmerian Sequence includes Eo-Ellesmerian
Lower Cretaceous to Cenozoic foredeep deposits
Box shows study area
Range front

Figure 16.1. Generalized geologic map of the northeastern Brooks Range showing regional anticlinoria, continental divide thrust front, and the study area.

penetrative structures, and are intruded by Devonian granites (Sable, 1977; Dillon et al., 1987b). Above the erosion surface, the Middle Devonian to Lower Cretaceous Ellesmerian Sequence (as defined by Lerand, 1973) is the depositional record of a south- to southwest-facing passive continental margin (Dutro, 1981; Moore et al., 1992). The age of the last mid-Paleozoic orogeny in northern Alaska is constrained by the abrupt change from polydeformed rocks below the erosion surface to less deformed rocks above. The entire succession was deformed during the Mesozoic to Cenozoic Brooks Range orogeny.

The study area is located at the headwaters of the Aichilik and Kongakut Rivers, southwest of Bathtub Ridge (fig. 16.1). In this part of the continental divide thrust front region, polydeformed lower Paleozoic rocks and the overlying Ellesmerian Sequence are exposed on the southeastern flank of a major east-plunging regional anticlinorium. Polydeformed Ordovician Romanzof chert (informal name) cores the anticlinorium (OCcp of Reiser et al., 1980). In the north, Mississippian Kekiktuk Conglomerate unconformably overlies the Romanzof chert with major angular discordance (fig. 16.2). In the south, a thick Middle Devonian to Mississippian stratigraphic succession consisting of the Ulungarat formation (Anderson, 1991), Mangaqtaaq formation (Anderson et al., 1992), and Kekiktuk Conglomerate has been thrust northward on the Aichilik pass thrust over the Romanzof chert and its thin overlying cover of Kekiktuk Conglomerate. The anticlinorium within the pre-Middle Devonian rocks and the folds and duplexes within the Middle Devonian and younger rocks are the result of Late Cretaceous(?) to Cenozoic deformation which formed the northeastern Brooks Range (Wallace and Hanks, 1990).

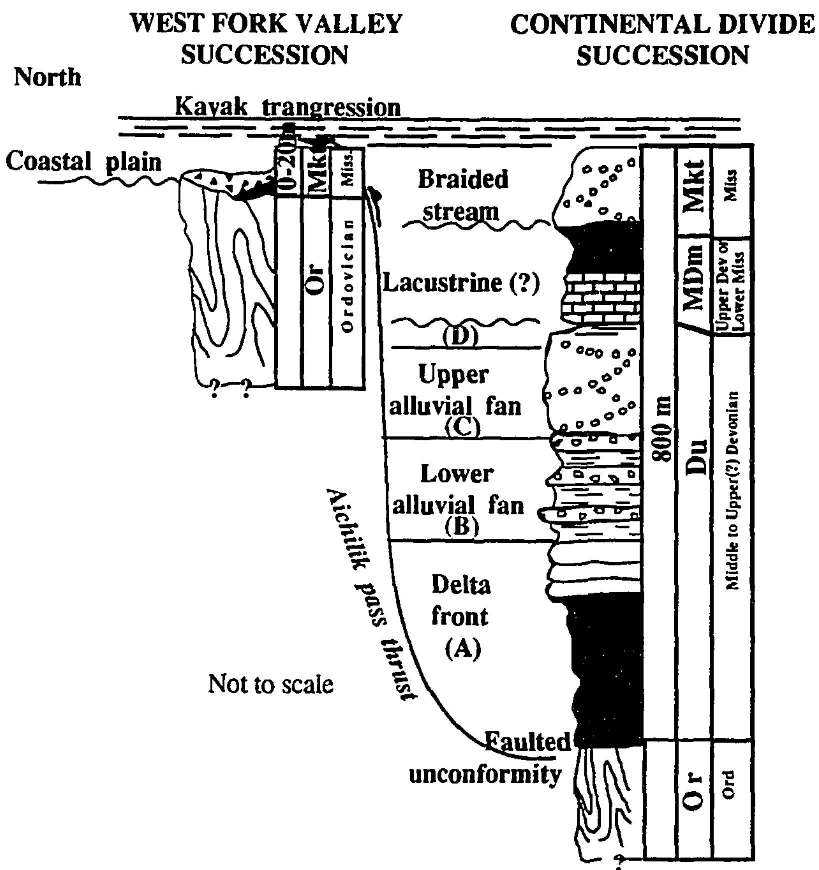


Figure 16.2. Generalized columns illustrating stratigraphic sequence exposed in for the study area showing differences in stratigraphy and depositional environmentswith abrupt southward increase in thickness of Middle Devonian to Mississippian clastic rocks across the Aichilik pass thrust. Displacement across the Aichilik pass thrust varies from an estimated few hundred meters to 2 km. Romanzof chert (Or), Ulungarat formation (Du), Mangaqtaaq formation (MDm), and Kekiktuk Conglomerate (Mkt).

Restoration of displacement on the Aichilik pass thrust shows that the Middle Devonian to Mississippian deposits form a southward-thickening clastic wedge. The Ulungarat and Mangaqtaaq formations in the lower part of this wedge have been interpreted to be syn-rift deposits (chapter 15). The abrupt change from thin clastic rocks of the Mississippian Kekiktuk Conglomerate in the footwall of the Aichilik pass thrust to a thick Middle Devonian to Mississippian clastic succession in the hangingwall is interpreted to reflect deposition across an ancient rift-basin margin (Anderson et al., 1992; see chapter 15).

This chapter summarizes the results of a structural study that characterizes the differences in structural history across the unconformities and the geometry of Brookian structures. The only previously published works on the area are the reconnaissance-scale maps of Reiser et al. (1980) and Brosge et al. (1976). For this study, detailed mapping at the scale of 1:25,000, analysis of minor structures, and measurement of stratigraphic sections were carried out to characterize the structural geometry and determine lateral variations in the stratigraphy in the field area.

16.B. STRUCTURAL DOMAINS

The major structures of the field area are north-vergent folds and thrust faults formed during Late Cretaceous(?) to Cenozoic Brookian deformation. Based on differences in structural style, the area is divided into four structural-stratigraphic domains (fig. 16.3). These differences correspond with and likely are controlled by differences in the stratigraphy of each domain (fig. 16.4). These relationships are shown in Table 16.1.

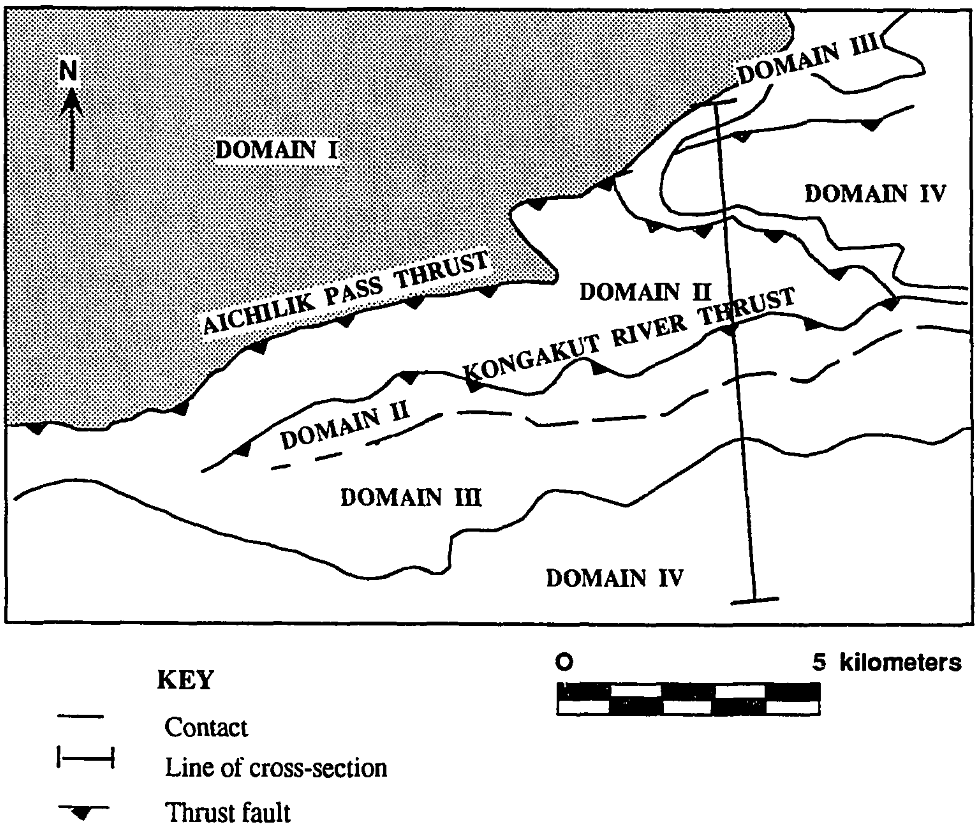


Figure 16.3. Generalized geologic map showing structural-stratigraphic domains in the study area. Line indicates approximate location of schematic cross-section in figure 16.4.

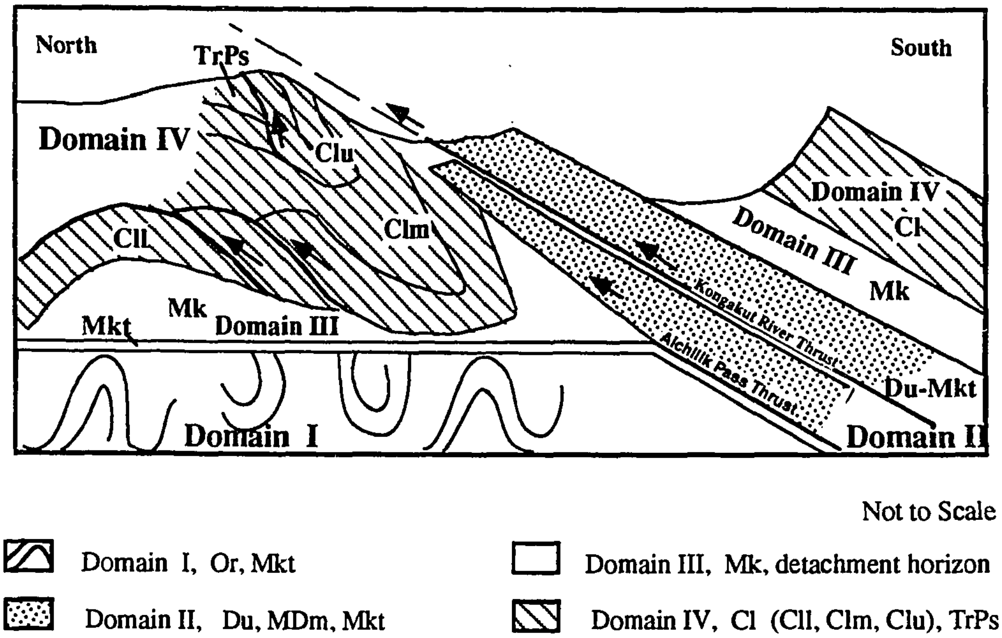


Figure 16.4. Schematic north-south cross-section illustrating structural geometry of each structural-stratigraphic domain. See Table 16.1 for formation names. Line of cross-section shown on fig. 16.3.

Table 16.1. Stratigraphic units and structural style in each domain north and south of the Aichilik pass thrust. The Aichilik pass thrust is the approximate position of the Middle Devonian to Mississippian rift-basin margin.

Structural - Stratigraphic Unit	North of Aichilik Pass Thrust	South of Aichilik Pass Thrust
DOMAIN IV Sadlerochit Group (TrPs) Lisburne Group (Cl)	Short wave-length detachment folds	Imbricate thrusts
DOMAIN III Kayak Shale (Mk)	Detachment horizon	Detachment horizon
DOMAIN II Kekiktuk Conglomerate (Mkt) Mangaqtaaq Formation (MDm) Ulungarat Formation (Du)	Not present	Duplex
DOMAIN I Kekiktuk Conglomerate (Mkt) Romanzof chert (Or)	Major regional anticlinorium	Not present

In the north, Domain I consists of the Romanzof chert and overlying thin Kekiktuk Conglomerate exposed in the regional anticlinorium. To the south, Domain II consists of a thick succession of Middle Devonian to Mississippian clastic rocks which have shortened by thrust duplication. Domain III consists of Kayak Shale which throughout the area serves as a detachment horizon. Domain IV consists of the Lisburne Group and Sadlerochit Group which shorten primarily by detachment folding.

16.B.1. Domain I

In the northwestern part of the map area, the regional anticlinorium is cored by Ordovician Romanzof chert. Mississippian Kekiktuk Conglomerate less than 30 meters thick depositionally overlies the chert with major angular discordance. This stratigraphic succession forms the footwall of the Aichilik Pass thrust and is defined as Domain I. The anticlinorium in Domain I is one of a series of large anticlinoria in the northeastern Brooks Range that have been interpreted to be fault-bend folds in a duplex between a floor thrust at depth in the pre-Middle Devonian rocks and a roof thrust in the Kayak Shale (Namson and Wallace, 1986; Wallace and Hanks, 1990).

The Romanzof chert is the structurally lowest unit in the field area, but forms topographic highs due to its resistance to erosion. The unit consists of 40-60% massive and bedded chert which occurs as rootless lenses in a phyllite matrix. Lenses or groups of lenses define mappable linear features that extend for kilometers in an east-west orientation. Individual chert lenses crop out for up to 100's of meters. Bedding and cleavage in the chert and phyllite are at a high-angle or sub-perpendicular to the overlying unconformity surface. The Romanzof chert is of inferred Ordovician age. This age assignment is supported by graptolites from presumably equivalent rocks along strike to the southwest in the Arctic quadrangle (Moore and Churkin, 1984; Moore et al., 1992) and an older age is precluded by the abundance of radiolaria in the bedded cherts.

The chert displays at least two generations of tight to isoclinal folds with variably plunging refolded axes. The fold geometry indicates significant shortening. It is not possible to distinguish D1 and D2 folds in most places. Structures are best exposed at several localities referred to on figure 16.5 as locations I, II, III, and IV. At locality I, tight to isoclinal chevron folds plunge steeply to the northeast (Appendix I.A) and are generally less than 4 m in wavelength. At locality II, the opposing asymmetry of small "S" and "Z" folds (< 0.5 m wavelength) across steep west-striking surfaces suggest parasitic folds on the limbs of a larger structure 10's of m in wavelength (Appendix I.B). Orientation of these limbs sub-perpendicular to the overlying unconformity suggests that the fold is sub-vertical. At locality II, small thrusts offset some of the chevron folds. Where seen, displacement across these thrusts is less than 0.5 m, suggesting out-of-syncline thrusting related to space problems. The general east-west orientation of the large synform at location II, with limbs oriented sub-perpendicular to the unconformity surface, suggests that the regional east-west structural grain of the chert "lenses" is a result of D2 deformation. Clearly refolded folds are exposed at localities III and IV (fig. 16.5 and 16.6). F1 fold axes refolded about F2 fold axes plunge steeply to the east and to the northwest (Appendix I.C and D).

The Mississippian Kekiktuk Conglomerate rests depositionally on the unconformity that truncates the underlying Romanzof cherts. The large chert lenses in the Romanzof chert are subperpendicular to the unconformity surface and to bedding in the Kekiktuk Conglomerate. This strong discordance aids in the recognition of the unconformity surface where massive cherty rocks are present both above and below. The

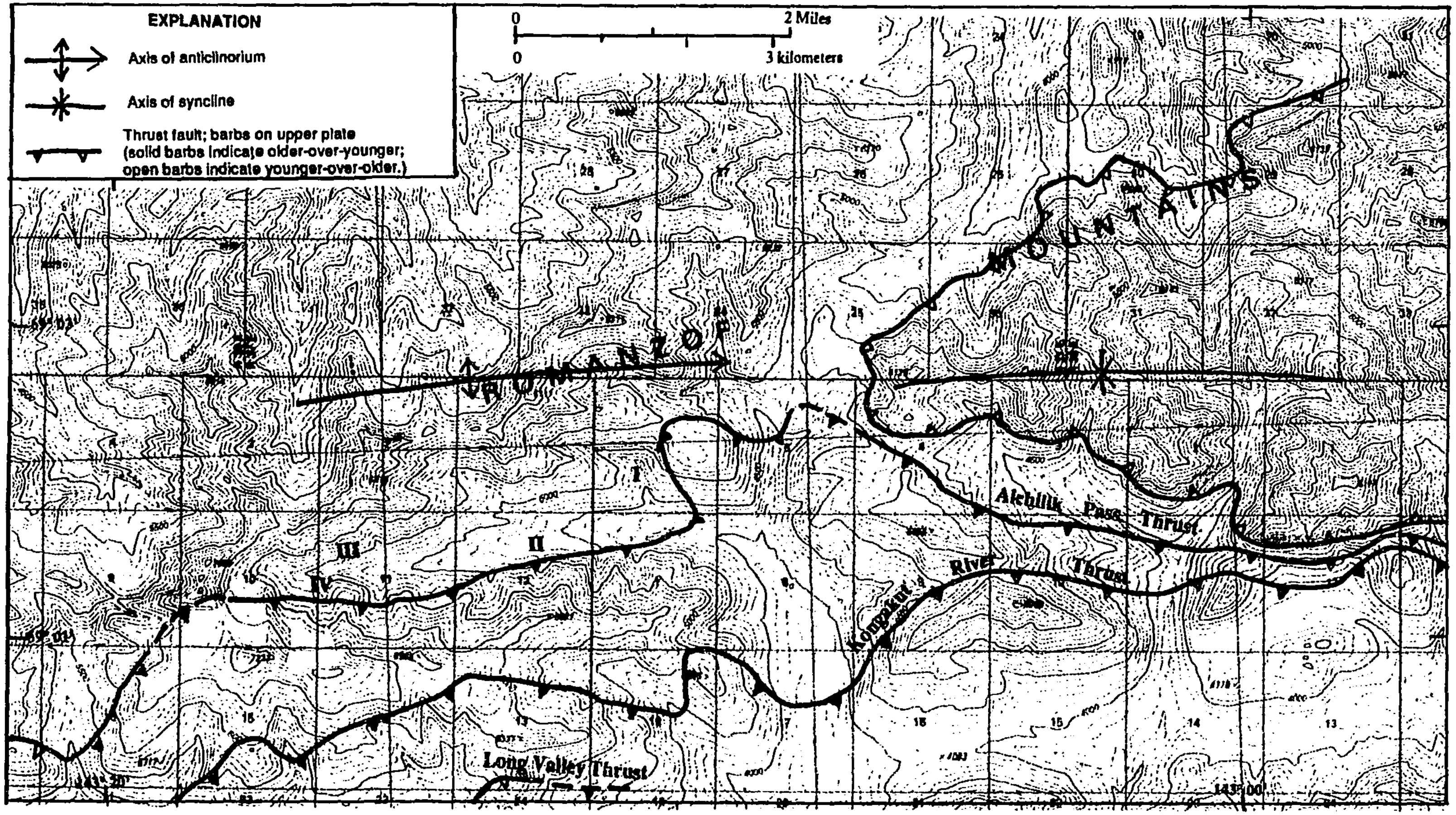
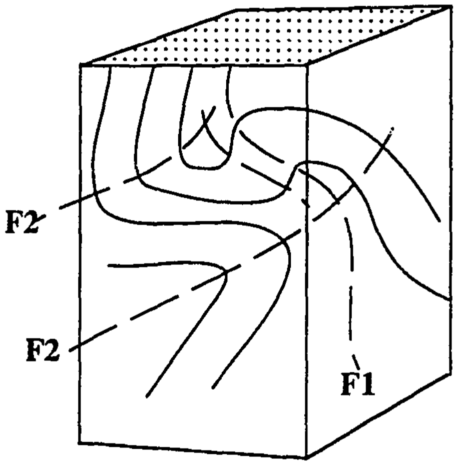


Figure 16.5. Simplified geologic map showing referenced locations.

(A)



(B)

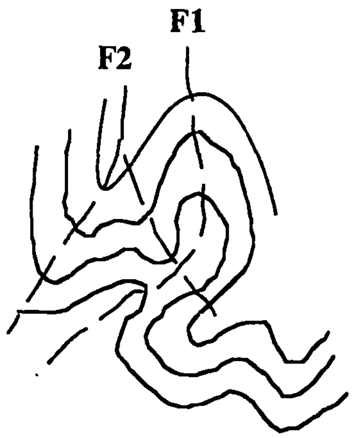


Figure 16.6. Line drawings of refolded folds in the Romanzof chert. F2 refolds F1. Figure A shows folds at location III on figure 16.5. Figure B shows folds at location IV on figure 16.5 Both folds < 4 m wavelength..

Kekiktuk Conglomerate has remained mechanically attached to the underlying Romanzof chert so that the two units have deformed during Brookian deformation as a single structural unit, which defines Domain I. Brookian shortening in Domain I is interpreted to have been accommodated by the northward displacement of one or more large horses in a duplex with a floor thrust at depth and a roof thrust in the Kayak shale. The unconformity and overlying Kekiktuk Conglomerate define the geometry of the upper surface(s) of the horse or horses which form(s) the regional east-plunging anticlinorium. In general, erosion of the Kekiktuk Conglomerate precludes determination of the precise geometry of the anticlines and of the number of horses. However, the eastern end of the regional anticlinorium defines a fault-bend fold that is a minimum of 8 km across.

16.B.2. Domain II

Domain II is in the hangingwall of the Aichilik pass thrust and comprises a different, but partially time equivalent, stratigraphic succession than in Domain I. Domain II consists of a Middle Devonian to Mississippian succession of terrigenous clastic rocks that includes the Ulungarat formation (Anderson, 1991), Mangaqtaaq formation (Anderson and Watts, 1992), and Kekiktuk Conglomerate. This stratigraphic succession is as much as 800 meters thick, but its base is defined by thrust faults everywhere in the study area. The stratigraphic succession in Domain II contains low-angle unconformities between units. The top of the Ulungarat formation is an erosional unconformity overlain in different places by the Mangaqtaaq formation or the Mississippian Kekiktuk Conglomerate. The Mangaqtaaq formation is also overlain with low-angle discordance by the Kekiktuk Conglomerate. There is no more than 5° to 10° discordance and no significant difference in deformation across these unconformities.

The lower member of the Ulungarat formation contains shallow-marine invertebrate fossils of Eifelian age (R.B. Blodgett, U.S. Geological Survey, personal communication, 1991). The Mangaqtaaq formation contains Late Devonian and/or Early Mississippian plant fossils (S. Mamay, U.S. Geological Survey, written communication, 1989). The Kekiktuk Conglomerate contains Early Mississippian plant fossils (R. Spicer, University of Oxford, personnel communication, 1990).

The rocks of Domain II have been shortened by thrust duplication. North-displaced thrust sheets dip to the south and are bounded by thrusts that generally parallel bedding in both the hangingwall and footwall. From north to south, the major thrust faults in the study area are the Aichilik pass and Kongakut River faults (fig. 16.3). These thrust sheets are interpreted to be horses in a duplex with a floor thrust in the lower Ulungarat formation and a roof thrust in the Kayak Shale. The lowest horse includes the thickest stratigraphic sequence and has been thrust northward on the Aichilik pass thrust directly onto strata of Domain I. In the western part of the study area, the Aichilik pass thrust is interpreted to be a faulted unconformity. In that area, the Middle Devonian Ulungarat formation in the hangingwall has been displaced along the contact with the Ordovician Romanzof chert in the footwall. To the east, the Aichilik pass thrust cuts stratigraphically higher in the footwall, successively displacing the hangingwall succession over Kekiktuk Conglomerate, cutting up section across the roof thrust in the Kayak Shale, and forming a footwall syncline in the Lisburne Group of Domain IV (Plate I). However, the actual thrust truncation of the Lisburne Group is not exposed in the study area but is inferred because the thrust projects above the immediately adjacent syncline in Domain IV. There is insufficient space between exposures of the thrust and the syncline for the thrust to do anything other than cut the syncline. Displacement across the Aichilik pass thrust is estimated to vary from a few 100 m in the west where it is interpreted to be a faulted unconformity to 1 or 2 km in the east where Middle Devonian Ulungarat formation overlies Mississippian Kayak Shale in the footwall. Farther south, the Kongakut River thrust (Wallace et al., 1988) and the Long Valley thrust duplicate the same stratigraphic succession (fig. 16.4).

The structure in Domain II is characterized by gentle southeast dips of bedding that reflect the dip of thrust sheets and, in the fine-grained sediments, by a well-developed cleavage that dips more steeply than bedding.(Appendix I (F, H, J, L, and M)). Stereographic projections of poles to bedding (S_0) and cleavage (S_3) define girdles about northeast-trending axes. These northeast -rending fold axes may reflect fault-bend folds and/or other thrust-related folds, although such folds have been eroded in most of the area.

16.B.3. Domain III

Domain III consists of the Kayak Shale, which has served as a major detachment horizon that commonly defines the boundaries between the other domains and separates thrust sheets in Domain II. The Kayak Shale is a fissile shale that varies in thickness from approximately 300 to 400 m in the Kongakut River thrust sheet to 100 m in the north, where it overlies Domain I. It probably has been structurally thickened in most places, so its true depositional thickness is uncertain. Because of its role as a horizon of slip, the Kayak Shale has been disrupted by minor folding, faulting, and penetrative strain.

Bedding and cleavage dip to the southeast and south (Appendix I (G, I, K, and N)). Penetrative slaty cleavage (S_3) characterizes the unit and is generally parallel to bedding (S_0). A second, spaced cleavage (S_4) is at a higher angle to bedding. Small folds less than 10 m in wavelength generally trend east-west and plunge to the southeast and east. Folds vary from upright to recumbent, open to tight. Asymmetrical folds are north-vergent. Large detachment folds and disharmonic folds characterize the upper Kayak Shale. These folds are defined by limestone beds in the upper Kayak Shale and are 10's to 100's of meters in wavelength.

The Kayak Shale has served as a detachment horizon that separates domains in which shortening has been accommodated in different ways. Most faults in the area cut up section to or from flats in the Kayak Shale. The unit has served as a detachment horizon for imbrication in Domains II and IV, and for the formation of detachment folds in Domain IV. For these reasons, it is assumed that slip has occurred somewhere within the unit throughout most of the map area. However, it is not generally possible to identify specific fault surfaces within the Kayak Shale. This is because the unit is a thick and lithologically homogeneous shale with few distinctive and stratigraphically continuous markers and is poorly exposed. Also, the unit commonly displays internal deformation in zones of significant thickness, suggesting that slip is commonly distributed over zones rather than on discrete fault surfaces. Thus, where faults cut up section to or from flats in the Kayak Shale, the continuation of those faults within the Kayak Shale is not generally illustrated on the map (Plate I).

16.B.4. Domain IV

Folds and thrust faults above a detachment horizon in the Kayak shale and with wavelengths of 100's of meters characterize Domain IV, which consists of the Mississippian-Pennsylvanian Lisburne Group and the unconformably overlying Permian-

Triassic Sadlerochit Group. The major structures of Domain IV are detachment folds formed above the Kayak Shale, which generally appears to be structurally thickened in the cores of anticlines. Thrust faults commonly have broken through the previously formed detachment folds, forming overturned footwall synclines and hangingwall anticlines. Thrust-truncation of existing folds locally has resulted in relationships that commonly are considered anomalous in thrust-faulted terrains, such as younger-over-older thrust faults and apparent discrepancies in sense of offset. Complications in this overall pattern have resulted from differences in structural behavior of different structural-stratigraphic units in the Lisburne Group during detachment folding and thrust propagation and displacement.

The Lisburne Group is divided into three units which show abrupt lateral changes in thickness and organization. Each of the three (Clu, Clm, Cll) has deformed as a separate structural unit within Domain IV. In different places, minor structures have formed before, during, or after major detachment folding and thrusting. The lowest unit (Cll) is a cliff-forming bioclastic limestone that in places shows pervasive replacement by black chert. It is less than 30 m thick and is depositionally absent from the southern part of the map area. Cll has behaved as a structurally competent unit. It is present in the footwall syncline of the Aichilik pass thrust, where shortening before folding locally was accommodated by displacement of horses in a minor duplex with a floor thrust in the Kayak shale and a roof thrust in Clm. In the northern part of the map area, Cll forms local minor, but spectacular, fault-bend folds, fault-propagation folds, and detachment folds.

Clm is relatively incompetent because it is thin-bedded and has a high percentage of argillaceous interbeds. The interval is approximately 300 to 400 m thick, but thickness is difficult to estimate due to structural complexity. The unit forms a detachment horizon between Cll and Clu. Thin competent beds within Clm form disharmonic detachment folds. Clu is a competent unit that has generally shortened by folding above Clm. In the structurally highest eastern part of the map area, Clu and the Sadlerochit Group have shortened by thrust duplication above Clm. Clu is approximately 200 to 300 m thick, but thickness is difficult to estimate due to erosion and structural duplication.

16.C. FRACTURES

Steep to subvertical fractures cut all other structures. Sterographic projections of poles to fracture surfaces are shown in Appendix I.O to Q. Most fractures strike NE-SW or NW-SE, although there is so much variability in orientation that distinct fracture sets are not apparent. Down-to-the-north normal faulting along the subvertical fractures is indicated by offset bedding and quartz fiber growth. Observed offsets are less than 10 cm. Where both subvertical and moderately dipping (40° to 60°) fractures are developed, the moderately dipping fractures offset the subvertical fractures. Quartz veins commonly fill the moderately dipping fractures.

16.D. INTERPRETATION OF STRUCTURES

Each structural-stratigraphic domain exhibits a distinct structural style, reflecting a different structural response to shortening by the mechanically distinct stratigraphy in each domain.

16.D.1. Domain I

Domain I is composed predominantly of a single stratigraphic unit, the Romanzof chert. The unconformably overlying Kekiktuk Conglomerate forms a thin veneer that deformed mechanically with the Romanzof chert. Brookian shortening in Domain I is interpreted to have been accommodated by displacement of large-scale horses in a duplex with a floor thrust at depth and a roof thrust in the Kayak Shale. The large size of horses in Domain I may reflect the great depth of the lower detachment and the fact that the Romanzof chert behaved as a single thick structural unit because of its previous strong deformation and a consequent lack of internal, thorough going, horizontal detachment horizons. The anticlinorium in Domain I is the southernmost of a series of similar major anticlinoria along the Aichilik River, each cored by large-scale horses composed of early Paleozoic rocks and unconformably overlying Kekiktuk Conglomerate (Hanks, 1993). The displacement of each horse is estimated to be on the order of 5-10 km (Hanks, 1993, fig. 10).

16.D.2. Domain II

Shortening in Domain II was accommodated by displacement of smaller-scale horses in a duplex with a floor thrust beneath marine shales of the lower Ulungarat formation and a roof thrust in the Kayak Shale. These horses consist of a succession of Endicott Group terrigenous clastic rocks, up to at least 800 m thick, that were deposited south of a rift-basin margin (see chapter 15). In its hangingwall, the Aichilik pass thrust cuts abruptly up section northward through the Ulungarat formation. To the east, the Aichilik pass thrust ramps across the Kayak Shale to a higher detachment horizon, perhaps the now eroded Kingak Shale, as has been documented elsewhere (Wallace et al., 1988; Wallace, 1989; and Homza, 1992). The ramping of the Aichilik pass thrust across the roof thrust to a higher detachment horizon may be related to Devonian normal faults along the rift-basin margin. Depositional termination of sub-Kayak clastic deposits against one or more basin-margin normal faults could deflect the northward propagating thrust fault upward at a high angle, causing the fault to ramp higher, rather than flattening in the Kayak Shale.

16.D.3. Domain III

Domain III consists of the incompetent Kayak Shale, which serves as the roof thrust for the duplexes in the underlying rocks of Domains I and II, and serves as the basal detachment for structures in Domain IV. The role of the unit as a detachment horizon is reflected by internal disharmonic folding, thrust-faulting, and penetrative cleavage.

16.D.4. Domain IV

Domain IV deformed independently of underlying domains and is characterized by a different, more complex, structural style. The domain consists mostly of the structurally competent Lisburne Group. Shortening was accommodated above the Kayak Shale detachment horizon by detachment folds and thrust duplication. Incompetent horizons within the Lisburne Group and Sadlerochit Group formed local detachment horizons which permitted the development of short-wavelength folds and local duplexes within Domain IV.

16.E. SEQUENCE AND AGE OF DEFORMATION

Four generations of structures have been identified in the study area and are summarized in Table 16.2. The D1 and D2 structures present in the Ordovician rocks of Domain I are absent in the unconformably overlying Middle Devonian and younger rocks. Thus, they document one or more pre-Middle Devonian contractional events. D3 and D4 structures record Late Cretaceous(?) to Cenozoic Brookian deformation and are present in the entire Ordovician through Triassic stratigraphic succession. D3 structures are best developed above the roof thrust of Domain I. D4 structures reflect formation of the anticlinorium in Domain I.

Apatite fission-track analysis from samples collected in Domains I, II, and III indicates a cooling age of about 59 Ma in the study area (P. O'Sullivan, written communication, 1991). The long track lengths reported indicate rapid cooling, probably due to uplift and consequent erosional unroofing. The similarity in ages from the Kongakut River thrust sheet, the Aichilik pass thrust sheet, and the underlying rocks of Domain I suggest that this cooling age dates formation of the anticlinorium in Domain I. These data are in agreement with a similar age for rapid uplift and unroofing at Bathtub Ridge (O'Sullivan et al., 1993). Formation of the duplex in Domain II probably predates that of the Domain I anticlinorium since the duplex structurally overlies and was folded during formation of the anticlinorium.

16.F. INFLUENCE OF THE DEVONIAN-MISSISSIPPIAN RIFT-BASIN MARGIN ON BROOKIAN STRUCTURES

The change in structural style that marks the continental divide thrust front corresponds approximately with the mid-Paleozoic rift-basin margin. Two distinct

Table 16.2. Summary of meso- and macroscopic structures in the study area.

		DESCRIPTION	INTERPRETATION
Brookian Orogeny	D 4	Limbs of large fault-bend fold defined by sub-perpendicular relation between Mkt and chert lenses in Or Fold > 8 km wave-length Thickness of fold > 1 km Thrust sheet > 1 km thick	Duplex with floor thrust at depth and roof thrust in Mk Significant structural relief of regional anticlinorium E-W orientation controlled by D2 structural grain
Brookian Orogeny	D 3	Domain II and III NE to E striking, moderately S-dipping bedding, cleavage,and spaced cleavage dip steeper than bedding Displacement on Aichilik pass thrust <2 km, Kongakut River thrust > 1 km Thrust sheets < 1 km thick Domain IV Large detachment folds with 100's m wave-length	So defines gently south-dipping thrust sheets Shortening accommodated in a duplex with a floor thrust below Du and a roof thrust in Mk. Above Mk by detachment folding and thrust duplication.
Major Regional Erosional Unconformities			
Pre-Middle Devonian Orogeny	D 2	Steeply NE plunging, tight to isoclinal, chevron folds Changes in asymmetry of folds associated with small thrust faults Defines E-W structural grain of large chert "lenses"	F1 folds refolded about F2 axes Suggests parasitic folds on limbs of large synform 100+ m wave-length
Pre-Middle Devonian Orogeny	D 1	Tight to isoclinal folds plunge steeply NW and NE, < 4 m wavelength	Earliest identified folding event, refolded during D2.

stratigraphic successions are present below the Kayak Shale detachment horizon. Each occupied a different position across the rift-margin (fig. 16.7). To the south, the southward-thickening wedge of syn-rift and early passive-margin deposits shortened as horses in a duplex. This stratigraphic succession is Domain II. The wedge-shaped depositional geometry of this stratigraphic unit resulted in termination of this duplex at the basin-margin where the floor thrust of the duplex cuts abruptly upward to the roof thrust in the Kayak Shale, and locally to an even higher detachment. The abrupt termination of the duplex resulted from depositional termination of the wedge and, possibly, upward deflection of the floor thrust against the ancient basin-margin. North of the rift-basin margin, the lithologically and thus mechanically different stratigraphic succession of Domain I deformed as thick horses in a different duplex with an apparently deeper detachment and significant structural relief. The Domain I anticlinorium is the southernmost of a series of anticlinoria that characterize the northeastern Brooks Range.

The change in structural style below the Kayak Shale detachment is reflected in a less abrupt, but distinct change in Domain IV above the Kayak. From the approximate position of the rift-basin margin to approximately 17 km to the north, Domain IV rocks show a progressive change in structural style from imbricate thrust faults to detachment folds. This change was recognized by Wallace (1992) and documented by Homza (1992).

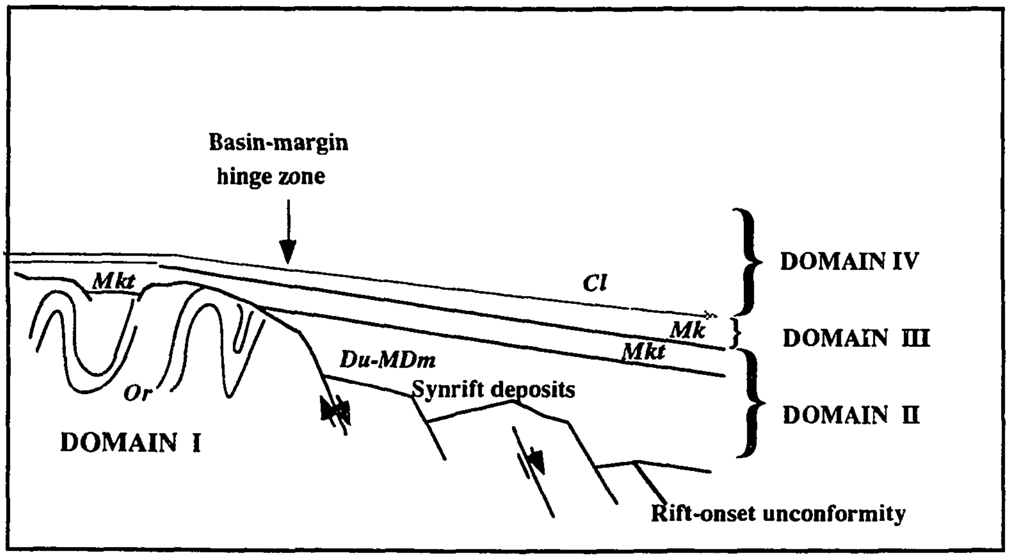


Figure 16.7. Schematic diagram of rift-basin margin showing relationship of structural domains in relation to tectonic elements across the interpreted rift-basin margin. Romanzof chert (Or), Ulungarat formation (Du), Mangaqtaaq formation (MDm), Kekiktuk Conglomerate (Mkt), and Lisburne Group (Cl).

16.G. SUMMARY AND CONCLUSIONS

Detailed mapping and structural analysis suggest the following conclusions:

1. At least two generations of structures within the Ordovician Romanzof chert have been truncated and overlain with angular unconformity by Middle Devonian to Mississippian clastic rocks. This constrains the latest major mid-Paleozoic contractional deformation to pre-Middle Devonian time.

2. The Middle Devonian through Triassic stratigraphic succession records only Brookian contractional deformation.

3. Where the Mississippian Kekiktuk Conglomerate was deposited directly on the erosional surface overlying the Romanzof chert (Domain I), the two deformed as a single structural unit during Brookian shortening. Shortening in Domain I was accommodated by displacement of large horses with a floor thrust at depth and a roof thrust in the Kayak Shale. The horse(s) in Domain I form a regional east-plunging anticlinorium.

4. In the south, a stratigraphic succession consisting of Middle Devonian to Mississippian clastic rocks (Domain II) forms south-dipping horses in a duplex with a floor thrust within or below the Ulungarat formation and a roof thrust in the Mississippian Kayak Shale.

5. The Kayak Shale (Domain III) serves as the roof thrust for the duplexes in the underlying rocks of Domains I and II, and serves as the basal detachment for structures in Domain IV. The role of the unit as a detachment horizon is reflected by internal disharmonic folding, thrust-faulting, and penetrative cleavage.

6. Detachment folds and thrust faults in the Lisburne Group and Sadlerochit Group (Domain IV) accommodate shortening above the Kayak Shale.

7. The change in structural style that is marked by the continental divide thrust front corresponds with a change in stratigraphy across the Devonian to Mississippian rift-basin margin at the base of the Ellesmerian rift to passive-margin succession.

8. The Domain II duplex ends at the rift-basin margin probably due to depositional "pinch out". The decollement stepped down across the rift-basin margin into a mechanically different unit (Domain I) which accommodated shortening as thick horses in a different duplex. These changes in the response of rocks below the Kayak Shale are reflected in a change in structural style above the Kayak. The structural style of Domain IV shows gradual northward change from imbricate thrust faults to detachment folds.

17. CONCLUSIONS

17.A. QUESTIONS ADDRESSED AND CONCLUSIONS

This study focused on north to south changes in the Devonian to Mississippian stratigraphic succession and coincident change in Cretaceous(?) to Cenozoic structural style in the region at the headwaters of the Kongakut and Aichilik Rivers, eastern Brooks Range. The Middle Devonian to Mississippian stratigraphic succession is the record of deformation, erosion and deposition that reflects a change in depositional and tectonic setting interpreted to reflect rifting and passive margin subsidence across a rift-basin margin. These relationships are significant to reconstruction of the early evolution of the Paleozoic continental margin of Arctic Alaska. The questions addressed by this research, with the resulting conclusions and interpretations, are each discussed below.

1. What is the age of the latest mid-Paleozoic contractional deformation in northeastern Alaska?

The unconformity surface truncating contractionally poly-deformed rocks of the Ordovician Romanzof chert is overlain by Middle Devonian and younger strata which record only Cretaceous(?) to Cenozoic contractional deformation. Rocks beneath the unconformity record the latest significant contractional deformation during mid-Paleozoic orogeny in northeastern Alaska. Regionally, the youngest rocks beneath the unconformity surface are Emsian (Early Devonian). My study indicates that the oldest rocks overlying the unconformity are the Eifelian (early Middle Devonian) shallow-marine deposits of the Ulungarat formation. These relationships tightly constrain the age of the latest mid-Paleozoic contractional deformation in the northeastern Brooks Range to Early Devonian time.

2. How does the character of the Middle Devonian to Mississippian stratigraphic succession change across the continental divide thrust front?

The terrigenous clastic succession deposited between the underlying complexly deformed Romanzof chert and the overlying carbonate platform rocks of the Lisburne Group forms a south- to southwest-thickening clastic wedge. The abrupt ten-fold increase in thickness is partially due to the presence of two formations at the base of the southern succession that are not present to the north, but also to the southward increase in thickness of the Kekiktuk Conglomerate and Kayak Shale. The thick succession was deposited in a rapidly subsiding basin south of a northern basin-margin highland. Clast composition indicates that the probable source of the coarse-grained detritus in the Devonian to Mississippian alluvial system was the underlying Romanzof chert, which in the north was apparently exposed to erosion from Middle Devonian to Early Mississippian time.

Deposition above the unconformity surface truncating the Romanzof chert began to the south in the continental divide succession during Eifelian (early Middle Devonian) time. Shallow-marine delta-front deposits of the lower part of the Ulungarat formation are overlain in turn by alluvial-fan deposits of the upper part of the formation and lacustrine or restricted shallow-marine deposits of the Mangaqtaaq formation.

Coastal-plain to marine shales of the Kayak Shale overlie and intertongue with retrograding deposits of the Kekiktuk Conglomerate, recording coastal retreat and drowning of a low-energy paleoshoreline. The deposits of the retrograding Kekiktuk fluvial system thin- and fine-upward and to the north, reflecting depositional onlap of the basin-margin high. Along the basin margin, thin, locally derived colluvium and fluvial deposits of the Kekiktuk Conglomerate and black coastal-plain and marine deposits of the Kayak Shale overlie the erosion surface that was the probable source of the thick, coarse-grained terrigenous clastic deposits to the south. The Kayak Shale records the initial deposition of a major marine transgression.

3. What was the tectonic setting during deposition of Middle Devonian to Mississippian terrigenous clastic rocks in the upper Kongakut River area?

Deposition of Devonian to Mississippian terrigenous clastic rocks record the cessation of earlier contractional deformation and onset of deposition in a rift to passive-margin tectonic setting. The sub-Ulungarat unconformity at the base of the continental divide succession separates complexly polydeformed rocks below from less deformed rocks above and thus marks a major change in tectonic setting. This unconformity is interpreted to be a rift-onset unconformity. The stratigraphic succession overlying the unconformity is characterized by 1) abrupt facies changes, 2) abrupt southward thickening associated with local evidence of active tectonism, 3) multiple unconformities merging northward toward the basin margin, 4) locally derived clastic deposits, and 5) closely associated shallow-marine, nonmarine, lacustrine(?), and volcaniclastic deposits. These characteristics are consistent with syn-rift deposition. The Kekiktuk Conglomerate and Kayak Shale onlap progressively older deposits northward toward the basin margin. To the north, Kekiktuk Conglomerate unconformably directly overlies pre-Middle Devonian polydeformed rocks of an extensive basin-margin highland. These relationships, combined with the depositional character of the Kekiktuk and Kayak, support the interpretation that these deposits record the onset of slower and more regionally extensive thermal subsidence of a passive margin. The sub-Kekiktuk unconformity is interpreted to be a post-rift unconformity.

4. How does the Middle Devonian to Mississippian stratigraphic succession in the study area fit into the regional and tectonic history?

The Middle Devonian to Early Mississippian record of terrigenous clastic deposition in the study area provides important insights into the depositional relationships between the allochthonous Endicott Group to the south and the parautochthonous to autochthonous Endicott Group to the north. A genetic relationship between the continental divide succession and the allochthonous Endicott Group is indicated by close similarities in lithology, provenance, depositional organization, sediment transport direction, and stratigraphic position. The continental divide succession records marginal marine deposition beginning earlier than in the allochthonous Endicott Group, and lacks definitive evidence for deposition during the dominant Late Devonian deposition of the allochthonous Endicott Group. However, these apparent discrepancies can be explained by progradation and across-strike variations in depositional geometry.

The west fork valley succession marks the southern edge of the parautochthonous to autochthonous Endicott Group. Although they are very different, the continental divide and west fork valley successions clearly are genetically related. Both successions include the Kekiktuk Conglomerate and the Kayak Shale, although they are thinner in the west fork valley succession and it lacks the Middle Devonian and younger depositional record present below the sub-Kekiktuk unconformity in the continental divide succession.

These relationships are best interpreted to represent the once laterally continuous record of deposition across a basin margin, now disrupted by north-vergent thrust faulting. This relationship between the continental divide and west fork valley successions provides a link between the allochthonous Endicott Group and the parautochthonous to autochthonous Endicott Group, if the continental divide succession is assumed to be genetically related to the allochthonous Endicott Group.

In the continental divide succession, Kekiktuk Conglomerate unconformably overlies Middle Devonian to lowermost Mississippian (?) rocks of the Ulungarat and Mangaqtaaq formations on a low-angle unconformity. Thus, progressively more time is represented by the record missing beneath the sub-Kekiktuk unconformity to the north, probably reflecting a progressively longer period of continuous erosion to the north. Clasts in the continental divide succession and the allochthonous Endicott Group apparently were derived at least in part from sources now exposed in the northeastern Brooks Range. These observations suggest that the region was a long-standing regional topographic high and site of erosion. In all three successions, coarse-grained fluvial deposition was gradationally succeeded by fine-grained marine deposition in the northward-transgressive Kayak Shale.

5. What are the differences in structural history across the unconformities within the Devonian to Mississippian stratigraphic successions?

No significant difference in structural history exists across the unconformities within the Devonian to Mississippian stratigraphic successions. Each of the contacts between the three Devonian to Mississippian formations is marked by a low-angle discordance, with underlying beds dipping more steeply to the south. These unconformities are truncated to the north beneath the sub-Kekiktuk unconformity along the basin margin. Such low-angle discordance can be a record of concurrent deposition and normal faulting and is consistent with syn-rift deposition seaward of the tectonic hinge zone of a passive margin. Contractional structures are consistent in character and orientation throughout the succession, which indicates that no contractional deformation affected the Middle Devonian and younger rocks before Cretaceous(?) to Cenozoic Brookian deformation.

6. What is the character and geometry of Cretaceous(?) to Cenozoic structures across the continental divide thrust front?

The change in structural style that marks the structural boundary between the north-central and northeastern Brooks Range coincides with the mid-Paleozoic rift-basin margin. The study area is the only place where the rift-basin margin is actually exposed, although it has been overprinted and disrupted by younger north-vergent fold and thrust structures. The initial response to shortening at the rift-basin margin was the formation of a duplex in the southward-thickening wedge of Middle Devonian to Mississippian syn-rift and early passive margin wedge deposits. This duplex terminates at the basin margin, where the southward-thickening wedge terminates and the floor thrust of the duplex cuts abruptly upward to the roof thrust in the Kayak Shale, and locally to an even higher detachment. This abrupt termination of the duplex resulted from depositional termination of the southward-thickening wedge against the ancient basin-margin. The floor thrust may have cut up section due to reactivation of steeply dipping pre-existing basin-margin faults or those faults may have deflected the thrust up section.

With continued shortening, the basal decollement stepped down into the thick polydeformed older strata underlying the rift margin. In the study area, this is the Romanzof chert, a thick assemblage apparently lacking internal horizontal detachment horizons as a result of pre-Middle Devonian deformation. Shortening was accommodated by northward displacement of thick horses in a duplex. Structural duplication of these horses created significant structural relief and required an equivalent amount of shortening in the Ellesmerian rocks above the roof thrust in the Kayak Shale. These horses form the major regional anticlinoria that are characteristic of the structural style of the northeastern Brooks Range north of the continental divide thrust front. The change in structural style below the Kayak Shale detachment is reflected above the Kayak in a more gradual northward change from imbricate thrust faults to detachment folds.

17.B. REGIONAL IMPLICATIONS OF THIS RESEARCH

The major change in regional structural history occurs across the erosional unconformity that marks the top of the Romanzof chert. The overlying Middle Devonian to Mississippian succession does not share the polydeformation and strong penetrative fabric of the underlying Romanzof cherts. This is significant because it constrains the latest major mid-Paleozoic contractional event to the pre-Middle Devonian.

The thick Middle Devonian to Mississippian succession probably is the proximal record of the fluvial clastic depositional system that reached its maximum extent with deposition of the Upper Devonian to Lower Mississippian allochthonous Endicott Group to the south and southwest. A genetic relationship between the continental divide succession and the allochthonous Endicott Group is indicated by similarities in lithology, provenance, depositional organization, sediment transport direction, and stratigraphic position as part of the south- to southwest-prograding nonmarine coarse-grained depositional system beneath the Kayak transgression. The uppermost deposits of the continental divide succession are equivalent to thin Lower Mississippian strata of the autochthonous Endicott Group that overlie the regional erosion surface above pre-Middle Devonian rocks to the north. Together, these terrigenous clastic deposits reflect rifting in Middle Devonian to Early Mississippian time to form the late Paleozoic-early Mesozoic south- to southwest-facing passive continental margin of Arctic Alaska. Differences among the different Endicott successions reflect different positions on the rifted margin.

17.C. SIGNIFICANCE OF THIS RESEARCH FOR THE STRUCTURAL STYLE OF FOLD AND THRUST BELTS

This research documents the influence of an older rift-basin margin on the structural style of a fold and thrust belt. The lateral change in stratigraphy across the rift-basin margin and the vertical stratigraphic succession that reflects its evolution have had a major influence on the structural behavior of rocks both above and below the rift-basin margin. The syn-rift depositional wedge south of the rift-basin margin has a very different structural style than the older, previously deformed rocks that formed the highland to the north of the basin-margin. The depositional wedge was structurally thickened above a detachment at its base by displacement of thrust sheets whose thickness and detachment horizons are controlled by the previously little-deformed stratigraphy. The rocks to the north were later displaced above a much deeper detachment, reflecting a lack of through-going, stratigraphically controlled detachment horizons because of the previous deformation, and possible reactivation of an older detachment surface. Normal faults associated with the rift-basin margin may have influenced later deformation either by reactivation as thrust faults or by deflection of thrust faults up-section where strata of the depositional wedge depositionally abut paleo-fault scarps to the north.

The rift-basin margin has influenced even overlying strata that were deposited after cessation of rifting and hence are depositionally continuous above the rift-basin margin. The margin has had an indirect effect because variations in the underlying structures have influenced overlying structures, and a direct effect because the overlying strata display differences in thickness and stratigraphy across the underlying rift-basin margin.

The cessation of rifting and onset of regional thermal subsidence has had a major influence on the structure of the region. The marine transgression that resulted from regional thermal subsidence led to deposition of the regionally extensive Kayak Shale. This unit has served as a major detachment horizon throughout the region that has allowed rocks above and below the detachment to deform with very different structural styles. The Lisburne Group formed as an onlapping carbonate platform as thermal subsidence continued and has served as the dominant structural member above the Kayak Shale detachment.

17.D. SUGGESTIONS FOR FURTHER STUDY

17.D.1. Stratigraphic Studies Along And Across The Rift-Basin Margin

Further stratigraphic studies along and across the outcrop belt of the continental divide succession to the west and south of the study area should focus on A) detailed mapping at 1:25,000 scale to determine the distribution of the formations, geometry of the unconformities, and evidence of syn-sedimentary normal faults and B) detailed measurement of stratigraphic sections to determine lateral facies changes, and C) study of sedimentary structures and depositional successions to determine environment of deposition. This research should be directed toward: 1) documenting the lateral variability of the stratigraphic succession along and across a rift-basin margin, and 2) understanding the southward transition into the allochthonous Devonian to Mississippian Endicott Group.

17.D.2. Sedimentological Studies Of The Mangaqtaaq Formation

The Mangaqtaaq formation is an example of an unusual high-stress, mixed siliciclastic-carbonate depositional setting. Documented examples of such settings from the ancient record are uncommon. Further study of this formation should focus on 1) detailed petrographic study to document the environment of deposition, 2) measurement of additional stratigraphic sections to document lithofacies lateral variability, 3) studies to determine character of lateral lithofacies contacts, and 4) collection of plant fossils to more tightly constrain age.

17.D.3. Structural Studies Of The Romanzof Chert

The older stratigraphic sequence below the Middle Devonian to Mississippian clastic wedge exhibits a complex, polyphase deformation history that is poorly understood. In the upper Kongakut River area, the Romanzof chert exhibits at least two generations of pre-Middle Devonian structures. Further structural studies of this unit should be directed toward recognition of the identifying characteristics of each generation of structures, documenting the geometry of those structures, and clarifying the pre-Middle Devonian deformation history. Continued study of the Romanzof chert should include detailed study of mesoscopic structures in critical areas. These studies could constrain interpretations of structural geometry and kinematic evolution, and may determine character, sequence, and vergence of deformational events.

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APPENDIX A. CONODONT DEPOSITIONAL AGE AND THERMAL DATA

Sample Number (USGS number)	Depositional Age	Cooling Age	Thermal Data	Temperature Range °C	Location N Lat	W Long	Elevation Meters (Feet)
Lisburne Group							
West Fork Valley							
89A - 4811 (USGS colln. 30877 - PC)	Chesterian	-----	4.5	190 - 300	69° 02.4'	143° 02.8'	1341 (4400)
89A - 4812 (USGS colln. 30878 - PC)	Chesterian	-----	4.5	190 - 300	69° 02.4'	143° 02.8'	1372 (4500)
90A - 147C (USGS colln. 31246 - PC)	early late Meramecian	-----	4 - 4.5	190 - 300	69° 01.4'	142° 54.6'	1372 (4500)
90A - 148A (USGS colln. 31247 - PC)	early late Meramecian - early Chesterian	-----	4.5	190 - 300	69° 01.52'	142° 54.7'	1418 (4650)
90A - 149A	earliest Morrowan	-----	4 - 4.5	190 - 300	69° 01.57'	142° 54.8'	1433 (4700)
Kongakut River							
90A - 130.129.5 (USGS colln. 31244 - PC)	early late Meramecian	-----	4.5	190 - 300	69° 0.0'	143° 02.3'	1067 (3500)
Kayak Shale							
West Fork Valley							
89A - 11E	-----	-----	NCR	-----	69° 02.9'	143° 07.1'	1494 (4900)
89A - 48G1 (USGS colln. 30876 - PC)	late Meramecian - early Chesterian	-----	4.5	190 -300	69° 02.4'	143° 02.8'	1311 (4300)
90A - 22A	-----	-----	NCR	-----	69° 03.2'	143° 06.2'	1402 (4600)
90A - 22B (USGS colln. 31240 - PC)	Early Mississippian - prob. late Kinderhookian	-----	4.5 - 5	190 - 300	69° 03.2'	143° 06.2'	1402 (4600)

Sample Number (USGS number)	Depositional Age	Cooling Age	Thermal Data	Temperature Range °C	Location N Lat	W Long	Elevation Meters (Feet)
<u>Kayak Shale (continued)</u>							
West Fork Valley (continued)							
90A - 59C	-----	-----	NCR	-----	69° 0.05'	143° 13.0'	1799 (5900)
90A - 144A (USGS colln. 31245 - PC)	middle Osagean - early Meramecian	-----	4 - 4.5	190 - 300	69° 01.3'	142° 54.6'	1341 (4400)
Kongakut River							
89A - 45F	post-Early Ordovician Paleozoic	-----	5.5 - 6	300 - 400	69° 02.9'	143° 07.1'	1494 (4900)
90A - 102B (USGS colln. 31241 - PC)	Early Mississippian prob. late Kinderhookian	-----	4.5 - 5	190 - 300	69° 0.8'	142° 54.6'	1555 (5100)
90A - 105B	-----	-----	NCR	-----	69° 0.8'	142° 54.6'	1372 (4500)
90A - 130.55 (USGS colln. 31242 - PC)	Osagean - early Meramecian	-----	4.5 - 5	190 - 300	69° 0.0'	143° 02.3'	1067 (3500)
90A - 130.85.5 (USGS colln. 31243 - PC)	Osagean - early Meramecian	-----	4.5 - 5	190 -300	69° 0.0'	143° 02.3'	1341 (4400)
<u>Mangaqtaaq Formation</u>							
Aichilik Pass							
88A - 10	-----	-----	NCR	-----	69° 01.2'	143° 09.0'	1341 (4400)
88A - 31C	-----	-----	NCR	-----	69° 01.4'	143° 07.2'	1372 (4500)
88A - 69A	-----	-----	NCR	-----	69° 01.3'	143° 06.9'	1250 (4100)
88A - 69B	-----	-----	NCR	-----	69° 01.3'	143° 06.9'	1250 (4100)
<u>Ulungarat Formation</u>							
Aichilik Pass							
88A - 1.0	-----	-----	NCR	-----	69° 00.2'	143° 21.5'	

Table A.1. Conodont analysis by Anita G. Harris, U.S. Geological Survey, Reston, VA. Reports 0-88-22, 0-88-22b, 0-90-10, 0-91-11. NCR = no conodonts recovered

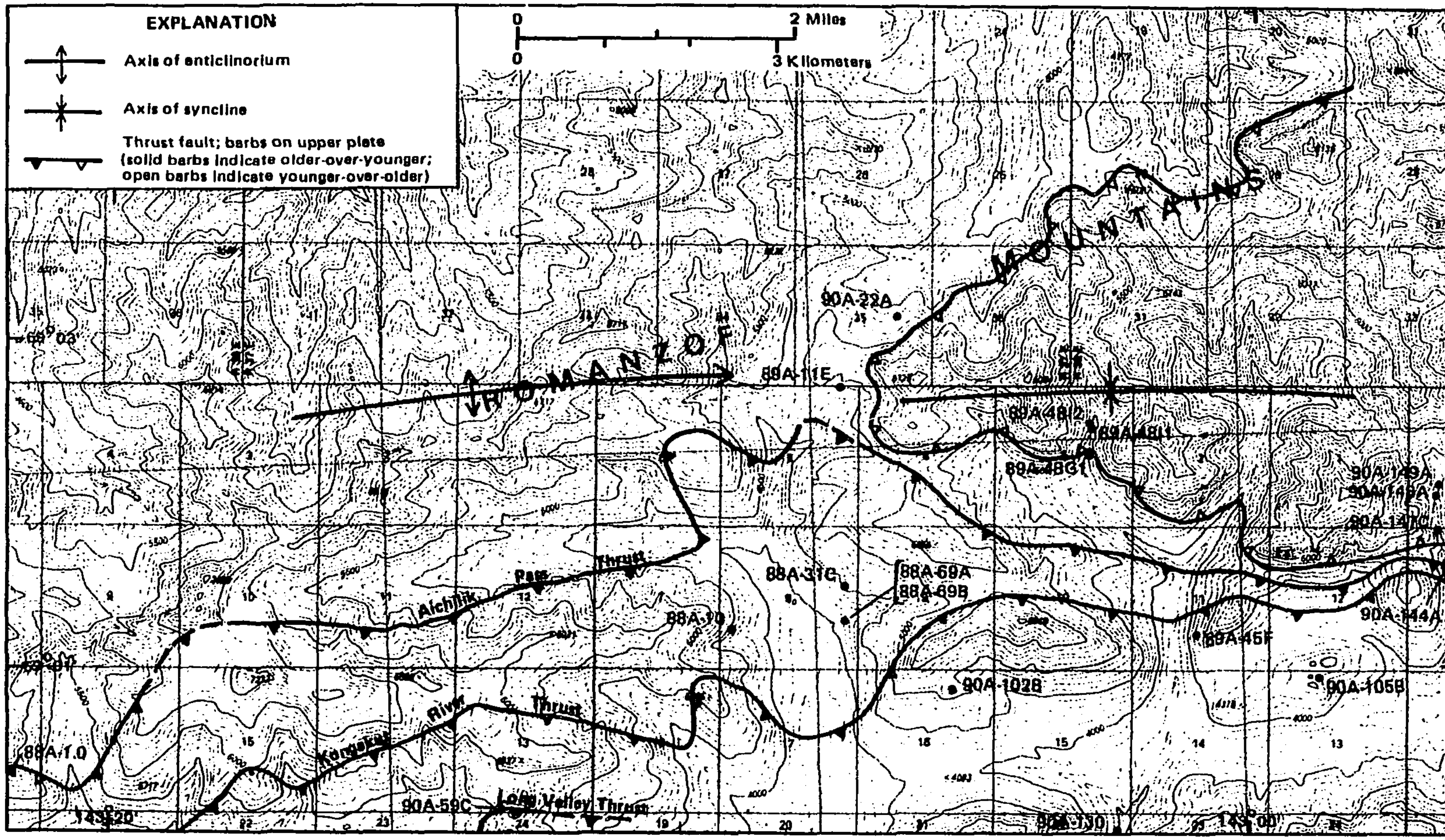


Figure A.1. Location map for conodont depositional age and thermal data. Simplified geologic map showing trace of major faults. See Plate 1 for detailed map. Southwest section, Demarcation Point (A-4) quadrangle, Alaska.

APPENDIX B. PALYNOLOGY DEPOSITIONAL AGE AND THERMAL DATA

Sample Number (GSC number)	Depositional Age	Cooling Age	Thermal Data	Temperature Range °C	Location N Lat	W Long	Elevation Meters (Feet)
<u>Kayak Shale</u>							
West Fork Valley							
88A - 44E (C - 195753)	-----	-----	4	> 300	69° 1.5'	143° 11.3'	1372 (4500)
89A - 15B (C - 195766)	-----	-----	NV	-----	69° 2.4'	143° 17.2'	1646 (5400)
89A - 33E (C - 195768)	-----	-----	NV	-----	69° 2.4'	143° 2.8'	1159 (3800)
89A - 77A (C - 195756)	-----	-----	4	> 300	69° 1.2'	143° 15.2'	1707 (5600)
89A - 77B (C - 195757)	-----	-----	4	> 300	69° 1.2'	143° 15.2'	1723 (5650)
90A - 2B (C - 195751)	-----	-----	4 ?	> 300	69° 3.0'	143° 6.9'	1494 (4900)
90A - 24A (C - 195752)	Tournaisian or Visean	-----	4	> 300	69° 3.4'	143° 4.8'	1311 (4300)
90A - 30B (C - 195763)	-----	-----	4 / 5	> 300	69° 1.7'	143° 10.6'	1159 (3800)
90A - 144B (C - 195765)	-----	-----	NV	-----	69° 1.7'	142° 56.8'	1372 (4500)
Kongakut River							
90A - 59A (C - 195761)	-----	-----	4 / 5	> 300	69° 0.1'	143° 13.4'	1677 (5500)
90A - 85C (C - 195764)	-----	-----	NV	-----	69° 0.1'	143° 18.1'	1585 (5200)
90A - 91A (C - 195760)	-----	-----	4 / 5	> 300	69° 59.6'	143° 18.8'	1372 (4500)
90A - 103B (C - 195759)	Visean	-----	4 / 5	> 300	69° 0.8'	143° 4.8'	1555 (5100)
90A - 130.47 (C - 195758)	-----	-----	5	> 300	69° 0.05'	143° 2.4'	1067 (3500)
<u>Kekiktuk Conglomerate</u>							
West Fork Valley							
89A - 24E (C - 195754)	-----	-----	4	> 300	69° 1.9'	143° 3.8'	1372 (4500)
89A - 43 - 4 (C - 195755)	-----	-----	4	> 300	69° 2.3'	143° 4.6'	1433 (4700)

Sample Number (GSC number)	Depositional Age	Cooling Age	Thermal Data	Temperature Range °C	Location N Lat	W Long	Elevation Meters (Feet)
<u>Mangaqtaaq Formation</u>							
Aichilik Pass							
88A - 10b - 2 (C - 195767)	-----	-----	NV	-----	69° 1.2'	143° 9.1'	1341 (4400)
89A - 67F (C - 195782)	-----	-----	5	> 300	69° 1.4'	143° 6.4'	1341 (4400)
89A - 67G (C - 195781)	-----	-----	5	> 300	69° 1.4'	143° 6.4'	1357 (4450)
89A - 67H (C - 195783)	-----	-----	5	> 300	69° 1.4'	143° 6.4'	1372 (4500)
89A - 104A (C - 195769)	-----	-----	NV	-----	69° 1.3'	143° 11.4'	1616 (5300)
90A - 29A (C - 195762)	-----	-----	NV	-----	69° 1.3'	143° 11.1'	1616 (5300)
91A - 26 (C - 204483)	-----	-----	5 ?	> 300	69° 02'	143° 07'	1372 (4500)
<u>Ulungarat Formation</u>							
Aichilik Pass							
88A - 1Q (C - 195775)	-----	-----	5	> 300	69° 0.4'	143° 21.7'	1829 (6000)
88A - 1Z - 2 (C - 195774)	-----	-----	5	> 300	69° 0.4'	143° 21.7'	1829 (6000)
89A - 103A (C - 195778)	-----	-----	5	> 300	69° 1.5'	143° 11.4'	1616 (5300)
89A - 103B (C - 195779)	-----	-----	5	> 300	69° 1.5'	143° 11.4'	1646 (5400)
89A - 107C (C - 195780)	-----	-----	5	> 300	69° 0.4'	143° 20.2'	1646 (5400)
89A - 113B (C - 195777)	-----	-----	5	> 300	69° 0.3'	143° 21.1'	1677 (5500)
90A - 31A (C - 195773)	-----	-----	NV	-----	69° 1.6'	143° 10.6'	1159 (3800)
90A - 31.79 (C - 195772)	-----	-----	5	> 300	69° 1.5'	143° 10.6'	1250 (4100)
90A - 93.39 (C - 195771)	-----	-----	NV	-----	69° 0.1'	143° 18.7'	1372 (4500)
Kongakut River							
89A - 47A (C - 195776)	-----	-----	5	> 300	69° 1.4'	143° 2.2'	1220 (4000)
90A - 112. - 7.5 (C - 195770)	-----	-----	5	> 300	69° 1.3'	143° 1.2'	1159 (3800)

Table B.1. The Thermal Alteration Index (TAI) was assessed from spore coloration previous to oxidation treatment. All samples contained organic material. The Palynology samples were evaluated by John Utting, Paleontology Subdivision, Institute of Sedimentary Petroleum Geology, Geological Survey of Canada. Report 3-JU-91.

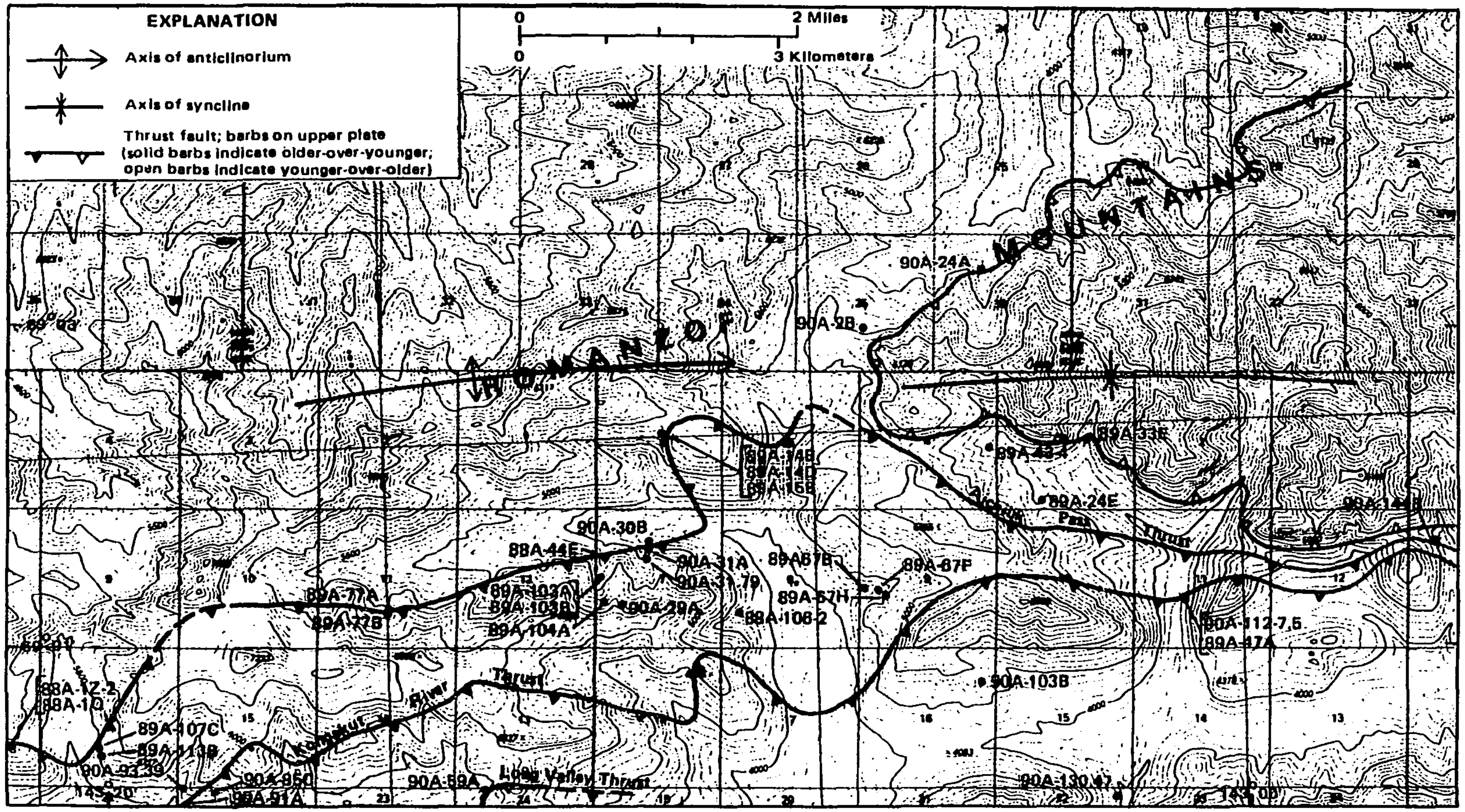


Figure B.1. Location map for palynology depositional age and thermal data. Simplified geologic map showing trace of major faults. See Plate 1 for detailed map. Southwest section, Demarcation Point (A-4) quadrangle, Alaska.

APPENDIX C. SHALE VITRINITE REFLECTANCE DATA

Sample Number	Depositional Age	Cooling Age	Thermal Data	Temperature Range °C	Location N Lat	W Long	Elevation Meters (Feet)
Kayak Shale							
West Fork Valley							
88A - 44E	-----	-----	4.2	> 300	69° 1.45'	143° 11.3'	1372 (4500)
89A - 14D	-----	-----	4.5 (4.18)	> 300	69° 2.4'	143° 17.2'	1646 (5400)
89A - 33E	-----	-----	3.8	> 300	69° 2.4'	143° 2.8'	1159 (3800)
89A - 77A	-----	-----	4.55	> 300	69° 1.2'	143° 15.2'	1707 (5600)
89A - 77B	-----	-----	4.4	> 300	69° 1.2'	143° 15.2'	1723 (5650)
90A - 2B	-----	-----	4.42	> 300	69° 3.0'	143° 6.9'	1494 (4900)
90A - 24A	-----	-----	4.37	> 300	69° 3.4'	143° 4.8'	1311 (4300)
90A - 30B	-----	-----	4.44	> 300	69° 1.65'	143° 10.6'	1159 (3800)
90A - 144B	-----	-----	3.87	> 300	69° 1.7'	142° 56.8'	1372 (4500)
Kongatuk River							
90A - 59A	-----	-----	4.57	> 300	69° 0.1'	143° 13.4'	1677 (5500)
90A - 91A	-----	-----	4.74	> 300	69° 59.6'	143° 18.8'	1372 (4500)
90A - 103B	-----	-----	4.89	> 300	69° 0.8'	143° 4.8'	1555 (5700)
90A - 130.47	-----	-----	4.88	> 300	69° 0.05'	143° 2.4'	1067 (3500)
Kekiktuk Conglomerate							
West Fork Valley							
89A - 24E	-----	-----	4.29	> 300	69° 1.9'	143° 3.8'	1372 (4500)
89A - 43 - 4	-----	-----	4.34	> 300	69° 2.3'	143° 4.6'	1433 (4700)
Mangaqtaaq Formation							
Aichilik Pass							
88A - 10b - 2	-----	-----	4.33	> 300	69° 1.2'	143° 9.1'	1341 (4400)
89A - 67B	-----	-----	NO	-----	69° 1.4'	143° 6.4'	1311 (4300)

Sample Number	Depositional Age	Cooling Age	Thermal Data	Temperature Range °C	Location N Lat	W Long	Elevation Meters (Feet)
Mangaqtaaq <u>Formation (continued)</u>							
Aichilik Pass (continued)							
89A - 67F	-----	-----	4.15	> 300	69° 1.4'	143° 6.4'	1341 (4400)
89A - 67H	-----	-----	3.72	> 300	69° 1.4'	143° 6.4'	1372 (4500)
89A - 104A	-----	-----	3.29	190 - 300	69° 1.3'	143° 11.4'	1616 (5300)
90A - 29A	-----	-----	4.40	> 300	69° 1.3'	143° 11.1'	1616 (5300)
Kongakut River							
90A - 85C	-----	-----	3.87	> 300	69° 0.1'	143° 18.1'	1585 (5200)
<u>Ulungarat Formation</u>							
Aichilik Pass							
88A - 1Z - 2	-----	-----	4.01	> 300	69° 0.35'	143° 21.65'	1829 (6000)
88A - 1Q	-----	-----	4.01	> 300	69° 0.35'	143° 21.65'	1829 (6000)
89A - 103A	-----	-----	4.6	> 300	69° 1.5'	143° 11.4'	1616 (5300)
89A - 103B	-----	-----	4.47	> 300	69° 1.5'	143° 11.4'	1646 (5400)
89A - 107C	-----	-----	4.17	> 300	69° 0.35'	143° 20.2'	1646 (5400)
89A - 113B	-----	-----	4.26	> 300	69° 0.3'	143° 21.1'	1677 (5500)
90A - 31A	-----	-----	4.69	> 300	69° 1.6'	143° 10.6'	1159 (3800)
90A - 31.79	-----	-----	4.41	> 300	69° 1.5'	143° 10.6'	1250 (4100)
Kongakut River							
89A - 47A	-----	-----	3.44	190 - 300	69° 1.4'	143° 1.2'	1220 (4000)
90A - 112. - 7.5	-----	-----	4.14	> 300	69° 1.3'	143° 1.2'	1159 (3800)

Table C.1. Vitrinite reflectance on shale was determined by U.S. Geological Survey, Denver as part of the U.S. Geological Survey Branch of Petroleum Geology Thermal Maturity Map of Alaska project.

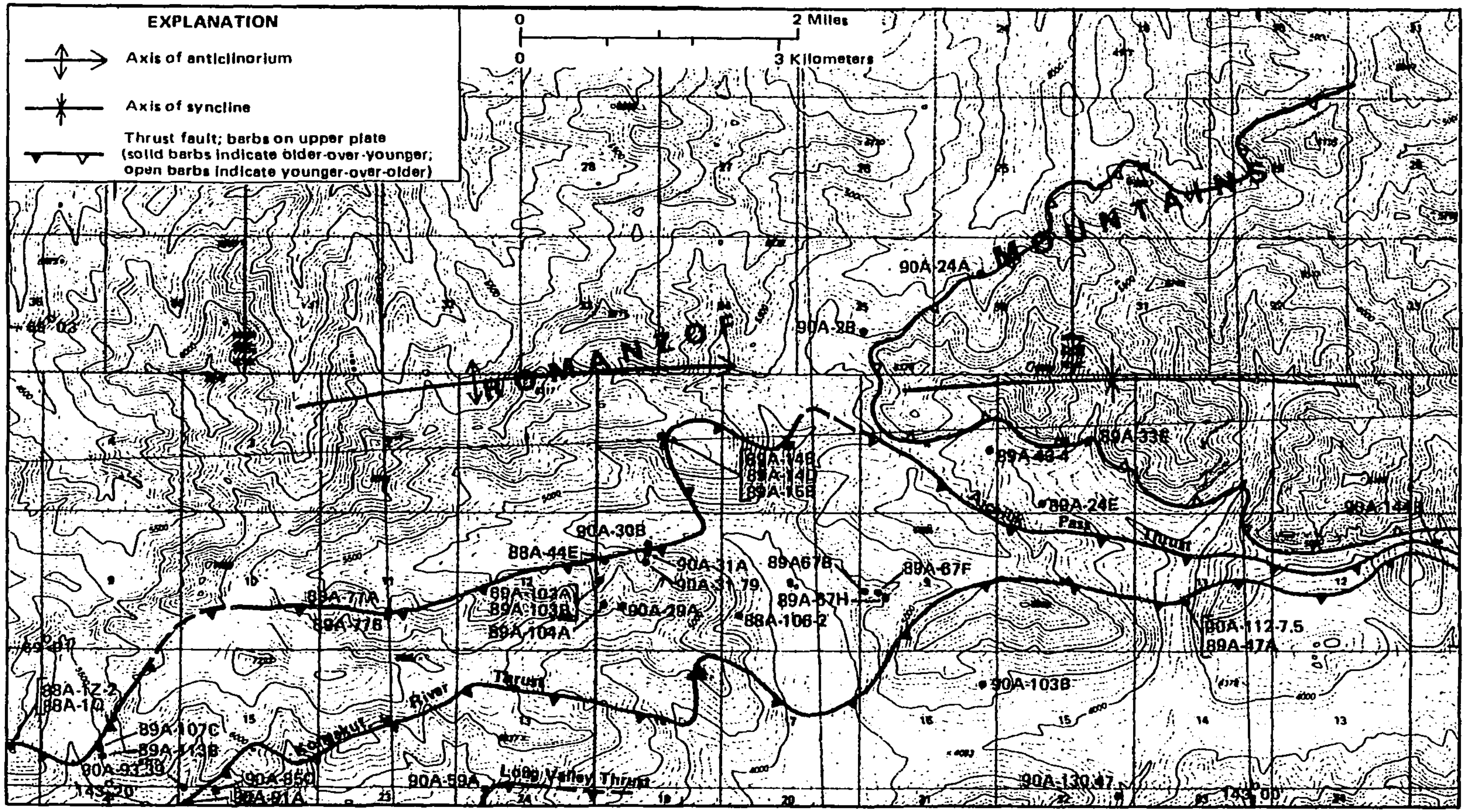


Figure C.1. Location map for shale vitrinite reflectance data. Simplified geologic map showing trace of major faults. See Plate 1 for detailed map. Southwest section, Demarcation Point (A-4) quadrangle, Alaska.

APPENDIX D. COAL VITRINITE REFLECTANCE DATA

Sample Number	Depositional Age	Cooling Age	Thermal Data	Temperature Range °C	Location N Lat	W Long	Elevation Meters (Feet)
Kayak Shale along contact with Kekiktuk Conglomerate							
West Fork Valley							
89A - 14C	-----	-----	4.4	> 300	69° 2.4'	143° 10.2'	1646 (5400)
89A - 14B	-----	-----	4.2	> 300	69° 2.4'	143° 10.2'	1646 (5400)
89A - 93	-----	-----	4.7	> 300	69° 1.3'	143° 17.2'	1921 (6300)
90A - 22e	-----	-----	4.2	> 300	69° 3.2'	143° 5.6'	1189 (3900)
90A - 9	-----	-----	4.5	> 300	69° 3.5'	143° 4.6'	1098 (3600)
Kongakat River							
90A - 129.1.7	-----	-----	4.2	> 300	69° 0.15'	143° 1.0'	1098 (3600)
Kekiktuk Conglomerate							
West Fork Valley							
90A - 14A	-----	-----	4.1	> 300	69° 4.0'	143° 2.8'	1372 (4500)

Table D.1. Vitrinite Reflectance on coal was determined by Gary Stricker, Branch of Coal Geology, U.S. Geologic Survey, Denver. The samples were prepared by grinding, embedding in epoxy, and polishing. Approximately 50 counts per sample were made to determine vitrinite reflectance in oil.

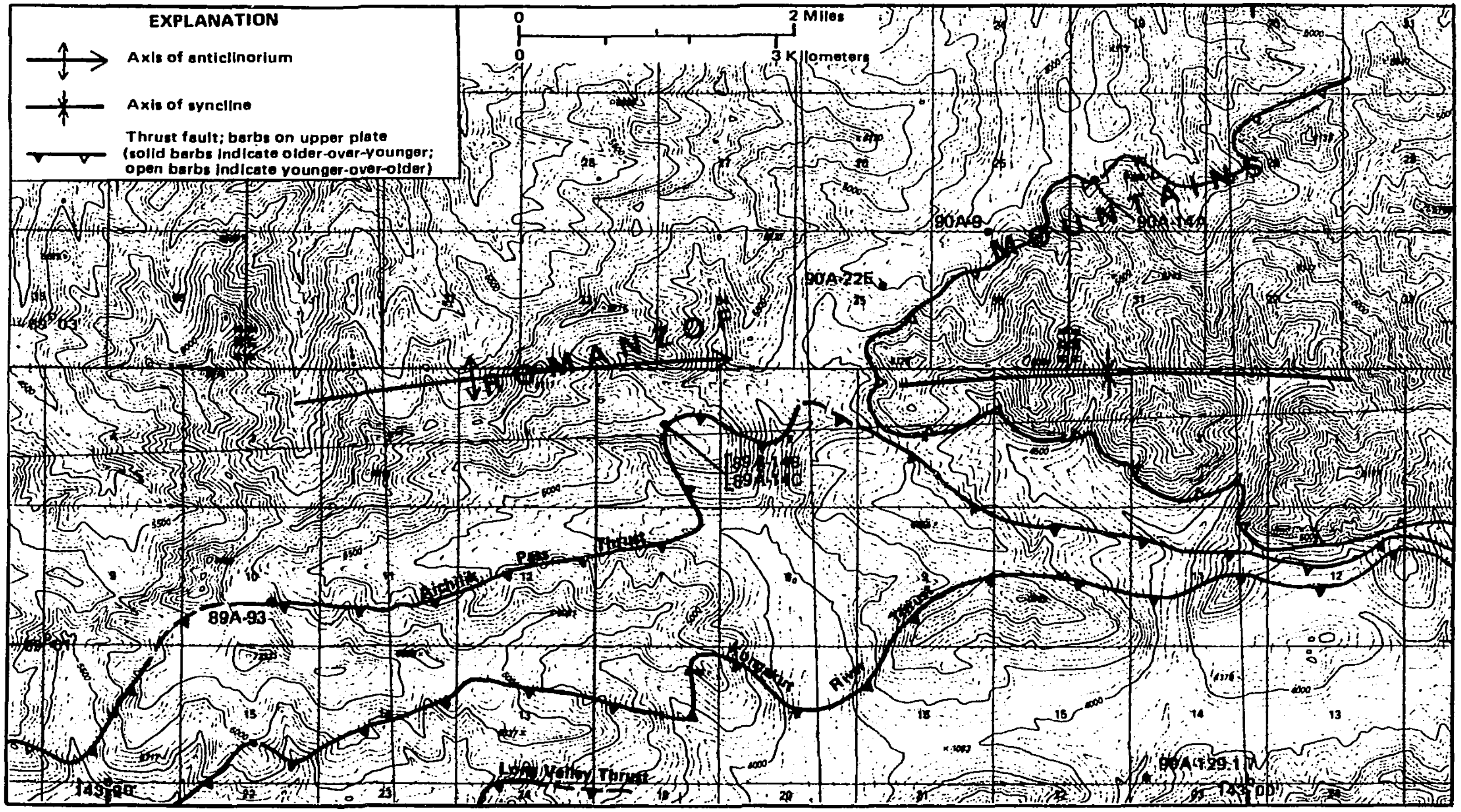


Figure D.1. Location map for coal vitrinite reflectance data. Simplified geologic map showing trace of major faults. See Plate 1 for detailed map. Southwest section, Demarcation Point (A-4) quadrangle, Alaska.

APPENDIX E. APATITE FISSION TRACK DATA

Sample Number	Depositional Age	Cooling Age	Thermal Data	Temperature Range °C	Location N Lat	W Long	Elevation Meters (Feet)
<u>Kayak Shale (sandstone)</u>							
Kongakut River							
90A - 129.1.5	-----	NA	-----	-----	69° 0.2'	143° 1.6'	1098 (3600)
90A - 137A	-----	55.4 ± 5.3	-----	-----	69° 0.1'	143° 2'	1067 (3500)
Long Valley							
90A - 61A	-----	51.0 ± 3.3	-----	-----	69° 0.0'	143° 12.4'	1707 (5600)
<u>Kekiktuk Conglomerate</u>							
West Fork Valley							
89A - 2B	-----	NA	-----	-----	69° 2.4'	143° 9.7'	1616 (5300)
89A - 14E	-----	NA	-----	-----	69° 2.3'	143° 10'	1662 (5450)
90A - 137C	-----	59.9 ± 5.7	-----	-----	69° 1.7'	143° 0.8'	1189 (3900)
Aichilik Pass							
89A - 7A	-----	61.5 ± 4.9	-----	-----	69° 2.0'	143° 9.8'	1646 (5400)
89A - 9B	-----	62.6 ± 7.3	-----	-----	69° 2.3'	143° 8.3'	1311 (4300)
89A - 128A	-----	61.4 ± 5.4	-----	-----	69° 0.7'	143° 19.8'	1860 (6100)
89A - 131 A	-----	57.3 ± 4.4	-----	-----	69° 0.4'	143° 19.8'	1829 (6000)
Kongakut River							
89A - 50B	-----	60.7 ± 7.7	-----	-----	69° 0.5'	143° 12.9'	1860 (6100)
89A - 52E	-----	62.3 ± 7.8	-----	-----	69° 0.7'	143° 13.5'	1951 (6400)

Sample Number	Depositional Age	Cooling Age	Thermal Data	Temperature Range °C	Location N Lat	W Long	Elevation Meters (Feet)
<u>Ulungarat Formation</u>							
Aichilik Pass							
89A - 128B	-----	50.0 ± 9.6	-----	-----	69° 0.8'	143° 19.8'	1890 (6200)
Kongakut River							
89A - 46B	-----	NA	-----	-----	69° 1.3'	143° 1.2'	1159 (3800)
90A - 112.30	-----	69.9 ± 14.4	-----	-----	69° 1.3'	143° 1.2'	1159 (3800)
90A - 150B	-----	50.6 ± 5.4	-----	-----	69° 1.4'	143° 56.4'	1280 (4200)

Table E.1. Apatite fission track analyses by Paul O'Sullivan, LaTrobe University, Australia.

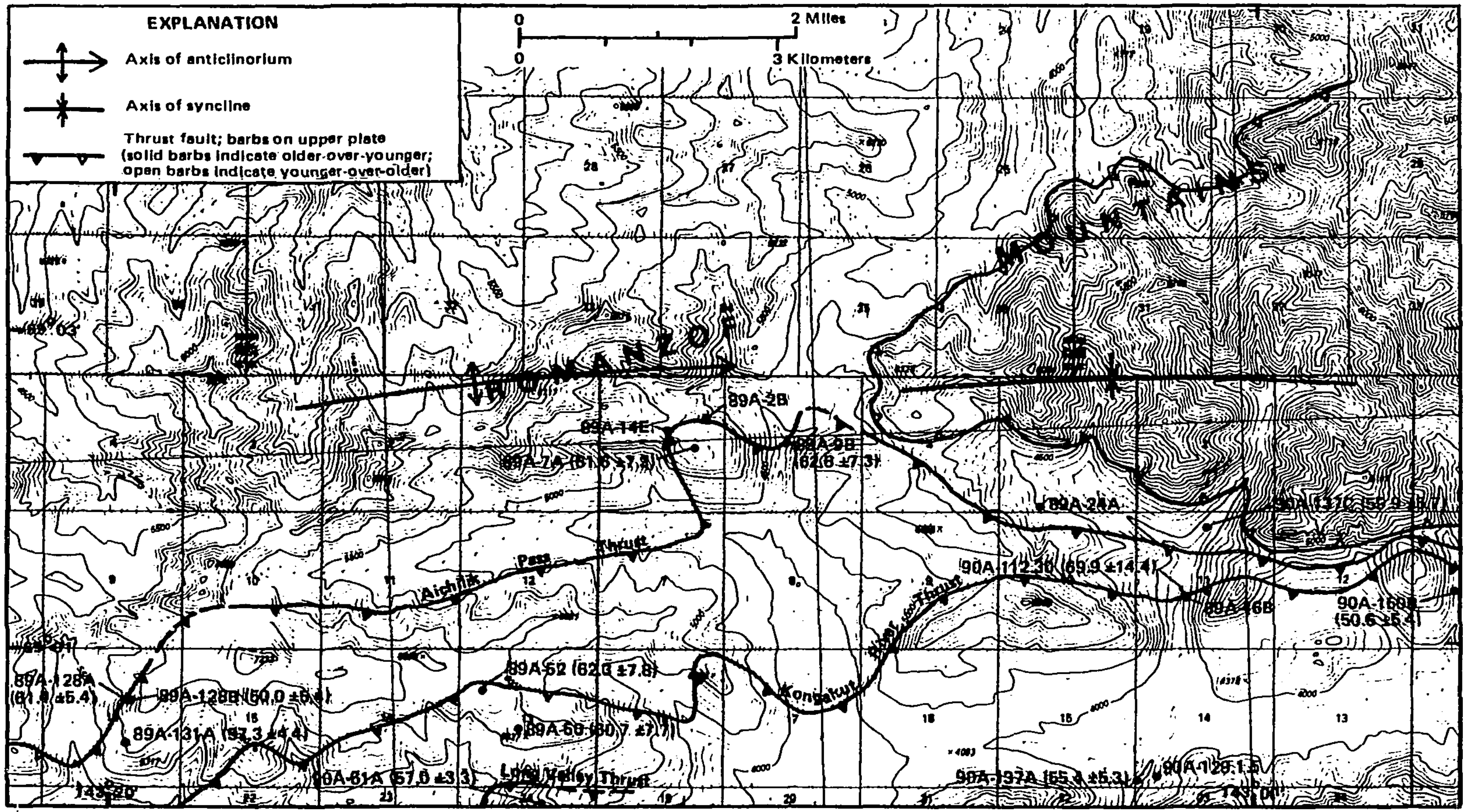


Figure E.1. Location map for apatite fission track data. Numbers in ( ) are cooling ages. Simplified geologic map showing trace of major faults. See Plate 1 for detailed map. Southwest section, Demarcation Point (A-4) quadrangle, Alaska.

APPENDIX F SANDSTONE POINT COUNT DATA

PETROGRAPHIC METHODS

Samples were cut perpendicular to bedding. Thin-sections measuring 2.5 by 4.5 cm were made allowing a grid spacing greater than the grain size to be used to count a minimum of 400 detrital grains on each slide. A grid spacing of 1 mm was used to avoid counting individual grains more than once. The Gazzi (1966) and Dickinson (1970) method of counting crystals greater than 0.0625 mm within lithic fragments as monocrystalline grains was used to reduce compositional variation dependent on grain size. Criteria for determining components, problems of diagenetic alterations, and counting method follow the criteria and methods discussed by Dickinson (1970, 1982), Graham and others (1976), Dickinson and Rich (1972), and Dickinson and others (1982).

Using a 0.66 by 1.32 mm grid and a 10X objective, a minimum of 400 detrital grains were counted from each thin-section. These data are reported in Table F.1. Calculated modal percentages are reported in Appendix G.

EXPLANATION FOR TABLE F.1

The following point count date are normalized for framework grains and matrix.

<u>Grain Types</u>

Qm Monocrystalline Quartz

Qp Polycrystalline Quartz

CHT Chert

Ls Sedimentary Rock Fragments

CO Calcite Cement

IND Indeterminate

ULUNGARAT FORMATION POINT COUNT DATA

NUMBER	Qm:	Qp:	Ch:	Ls:	CO:	Sec:	Unid:
88A-1X	32	5	364	---	---	12	5
90A-31.74	147	4	252	5	10	15	8
90A-31.140	28	3	371	6	8	---	7
90A-31.145	63	13	324	14	---	---	8
90A-31.152	5	1	398	---	14	7	2
90A-31.159C	24	8	371	5	---	13	2
90A-31.159D	33	12	355	---	---	35	10
90A-31.240	56	23	322	---	28	4	---
90A-31.259	79	27	292	---	---	14	2
90A-31.264.5	90	9	276	27	---	4	9
90A-31.269	5	5	437	---	---	20	2
90A-112.6.5	5	11	389	---	25	5	4
90A-112.11.7	11	8	384	---	10	6	4
90A-112.30.4	14	17	369	---	---	15	5
90A-112.39.5	44	12	350	10	---	1	12
90A-112.127	5	6	389	---	---	2	4

Table F.1. Ulungarat Formation point count data.

APPENDIX G. SANDSTONE DETRITAL MODES

EXPLANATION FOR TABLE G.1

Point count data from Appendix F are normalized to the following three component systems: Q-F-L and Qm-F-Lt.

Q-F-L

Q = Qm + Qp + chert

F = Plagioclase feldspar + potassium feldspar

L = Sedimentary lithic grains

Qm-F-Lt

Qm = Monocrystalline quartz

F = Plagioclase feldspar + potassium feldspar

Lt = Polycrystalline quartz + chert + sedimentary lithic grains

ULUNGARAT FORMATION DETRITAL MODES

	MATURITY			PROVENANCE		
Number	Q	F	L	Qm	F	Lt
88A-1X	100	0	0	8	0	92
90A-31.74	98.8	0	1.2	36	0	64
90A-31.140	98.5	0	1.5	6.9	0	93.1
90A-31.145	96.6	0	3.4	15.2	0	84.8
90A-31.152	100	0	0	1.2	0	98.8
90A-31.159C	98.8	0	1.2	5.9	0	94.1
90A-31.159D	100	0	0	8.2	0	91.8
90A-31.240	100	0	0	14	0	86
90A-31.259	100	0	0	19.8	0	80.2
90A-31.264.5	93.3	0	6.7	22.4	0	77.6
90A-31.269	100	0	0	1.1	0	98.9
90A-112.6.5	100	0	0	1.2	0	98.8
90A-112.11	100	0	0	2.7	0	97.3
90A-112.30	100	0	0	3.5	0	96.5
90A-112.39	97.6	0	2.4	10.6	0	89.4
90A-112.127	100	0	0	1.2	0	98.8

Table G.1. Ulungarat Formation detrital modes.

APPENDIX H. MEASURED STRATIGRAPHIC SECTIONS

KEY TO SYMBOLS

Rock Type

- Limestone
- Sandstone
- Conglomerate
- Mudstone and Siltstone
- Covered

Carbonate Classification

G	Grainstone
P	Packstone
W	Wackestone
M	Mudstone

Grain Size

Gravel (G)	Cobbles (C) Pebbles (P)
Sand (S)	Coarse (C) Medium (M) Clay (C)
Mud (M)	Siltstone (S) Clay (C)

Grain Type

- Gastropod
- Ostracod
- Algae
- Intraclasts
- Peloid
- Bryozoan
- Brachiopod
- Bivalve
- Trilobite
- Foraminifer
- Sponge spicules
- Pelmatozoan
- Calicisphere
- Ostracod
- Unidentified shell fragments
- Plants
- Py Pyrite

Sedimentary Structures

- Trough Cross-stratification
- Horizontal Cross-stratification
- Low-angle Cross-stratification
- Ripple Cross-stratification
- Wavy Lamination
- Bioturbation

LIST OF MEASURED SECTIONS

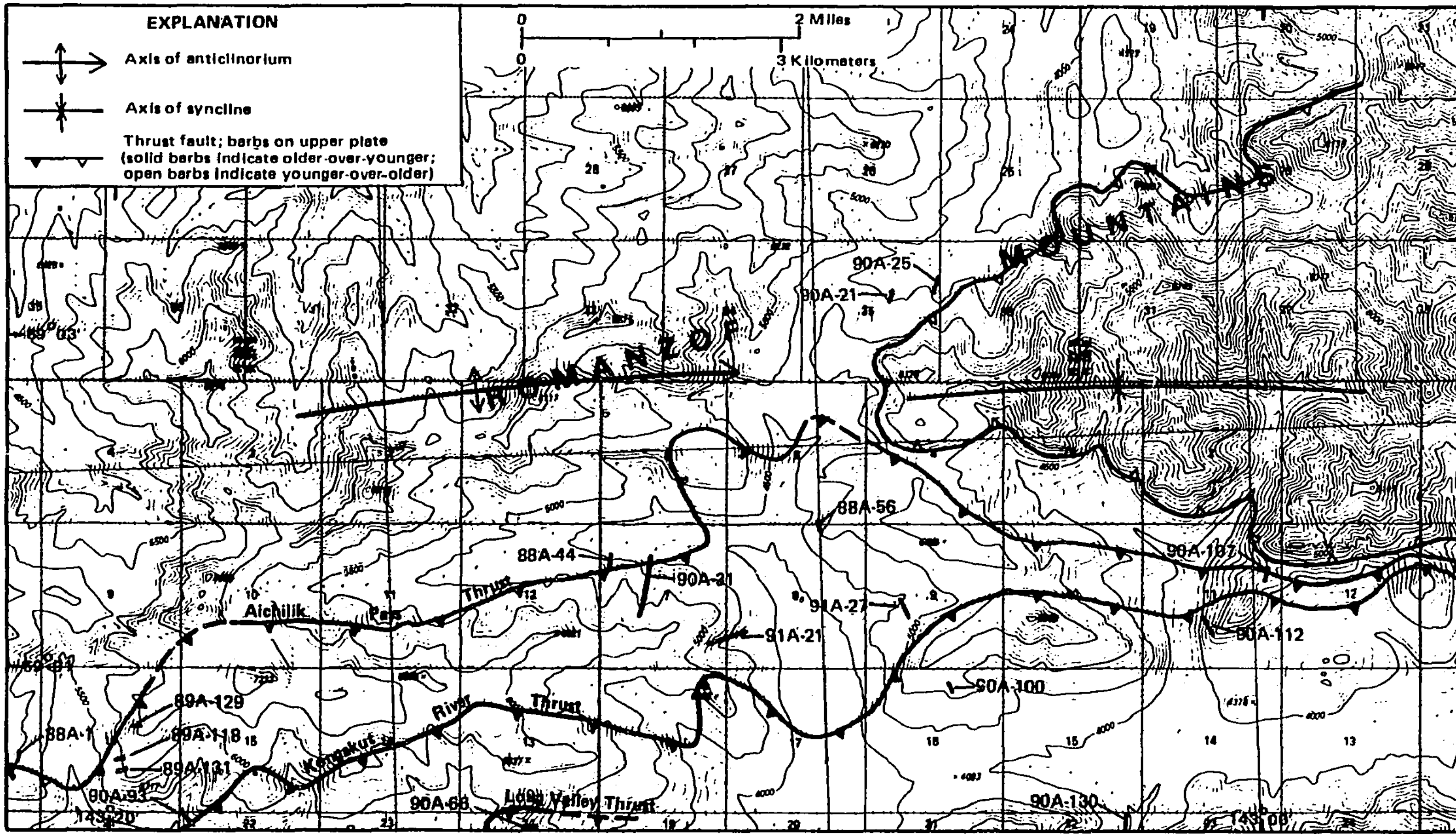
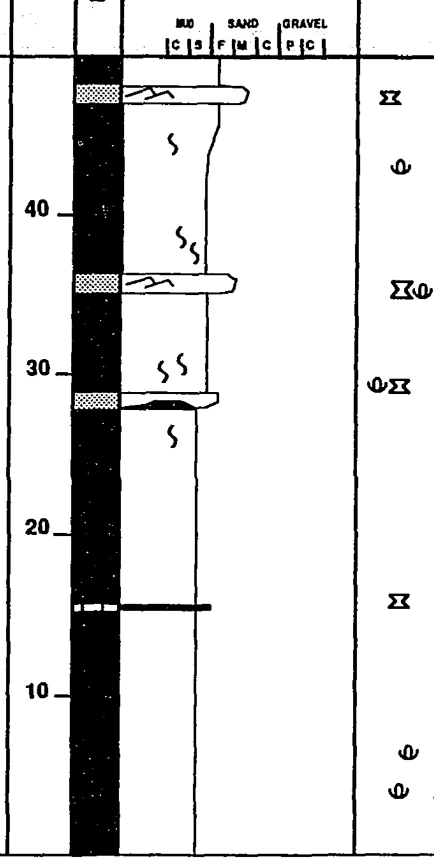


Figure F.1. Location map for measured sections. Simplified geologic map showing trace of major faults. See Plate 1 for detailed map. Southwest section, Demarcation Point (A-4) quadrangle, Alaska.

Measured section 88A-1 — Page 1 of 2

Section 16, T.5 S., R.37 E., Demarcation Point (A4) quadrangle, Alaska

Measured by A. Anderson and W. Wallace

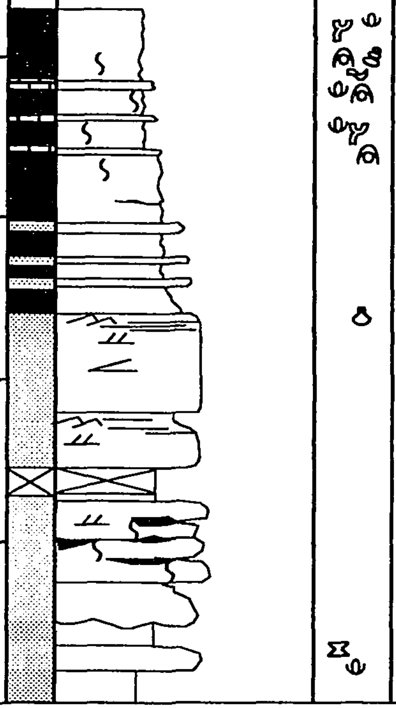


PERIOD	EPOCH	FORMATION	MEMBER	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN	EIFELIAN	ULUNGARAT	A	(27 - 47 m) Mudstone upward coarsening to siltstone interrupted at irregular intervals by infrequent sandstone beds: Mudstone and siltstone are black to dark gray; weathers black to steel -gray; in places bioturbated; fissile. Sandstone is dark gray, weathers gray and orange-brown: calcareous, graded, some ripple cross-lamination; resistant, laterally discontinuous beds 0.5 to 2 cm thick with erosional bases; abundant broken fossils. Interval forms a steep slope.	Subaqueous delta front
				(15 - 27 m) Mudstone, weathers to green-gray clay; forms steep slope.	
				(0 - 15 m) Soil cover with shale chips; brown, weathers red-brown to gray; soil development greater than 20 cm; abundant Lingula brachiopod fossils; saddle marking contact with Or. Base of section covered. Base of measured section placed at north edge of saddle at beginning of red-brown weathering zone.	

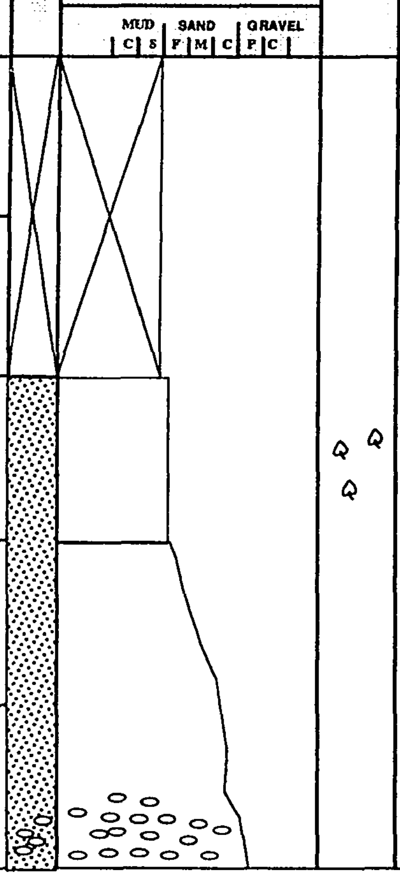
Measured section 88A-1 — Page 2 0f 2

Section 16, T. 5 S., R. 37 E., Demarcation Point (A4) quadrangle, Alaska

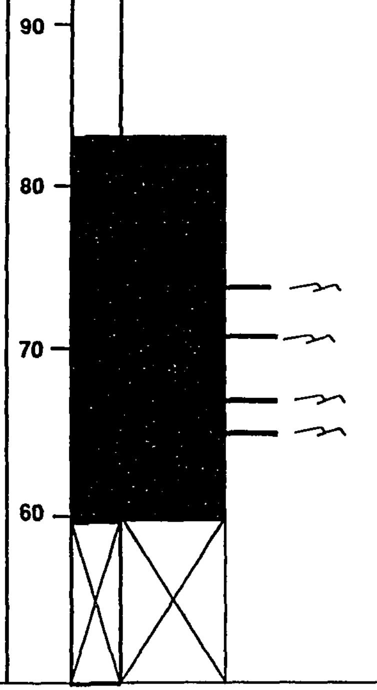
Measured by A. Anderson and W. Wallace

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE / GRAPHIC COLUMN (MUD C S; SAND F M C; GRAVEL F C) / FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN	EIFELIAN	ULUNGARAT	A	90, 80, 70, 60		Top of measured section placed at top of 0.5 m ledge containing uppermost maroon mudstone. Overlain by dip-slope with low outcrops of chert arenite in fining-upward intervals.	
						(76 - 93 m) Interbedded mudstone, siltstone, and thin-beds of limestone: Below 82 m siltstone, gray; thin beds of fossiliferous, orange-yellow limestone. Above 82 m mudstone and siltstone, weathers maroon, bioturbated.	Low-energy environment interdistributary bay(?) with storm-washover deposits
						(64 - 76 m) Chert arenite gray, weathers rusty-orange; 2 intervals each overlain by mudstone. Massive bedded sandstone in lower part of each interval, beds 2-4 cm thick at top. Resistant ledges at top of steep slope.	High-energy environment bay-mouth bar(?)
						57.5 - 64 m Chert arenite and grit: weathers light gray to rusty-orange; medium bedded with thin (<0.5 cm) black mudstone; bioturbation of sandstone immediately below mudstone.	
						47 - 57.5 m Siltstone and chert arenite: gray, weathers maroon to rusty-orange; amalgamated sandstone intervals contain beds 0.5-2 cm thick; coquina 2 cm thick at 48 m.	Subaqueous delta plain

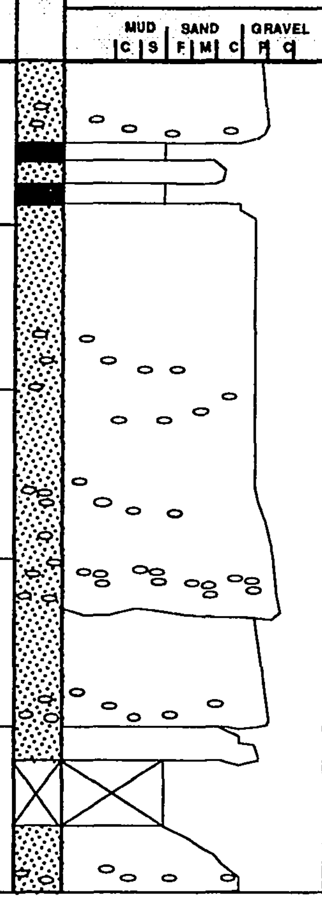
Measured section 88A-44
Section 7, T. 5 S., W. 38 E., Demarcation Point quadrangle (A-4), Alaska
Measured by A. Anderson and T. Osterkamp

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE / GRAPHIC COLUMN / FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
MISSISSIPPIAN		KEKIKTUK CONGLOMERATE		40 30 20 10		(30 - 60) Covered (20 - 30 m) Siltstone and very fine-grained sandstone: dark gray, abundant plant fossils, silicified burrows. (0 - 20 m) Chert breccia to pebble conglomerate and chert arenite: black, gray, white, and purple-raspberry colored chert pebbles. The basal bed is massive clast-supported breccia which becomes conglomeratic within 1 m of the base and fines upward to fine-grained sandstone. Above the basal 2 m thick interval, beds 1 to 2 m thick fine upward from conglomerate and/or pebbly sandstone to fine-grained sandstone. Base of section placed at top of massive chert of the Romanzof chert.	Braided fluvial system in wet coastal-plain.

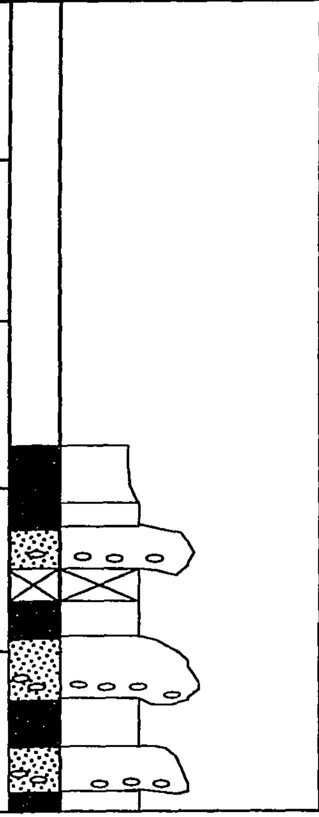
PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN (MUD: C, S; SAND: F, M, C; GRAVEL: P, C)	FOSSILS	Measured section 88A-44 Page 2 of 2 Section 7, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska Measured by A. Anderson and T. Osterkamp	
								DESCRIPTION	ENVIRONMENT OF DEPOSITION
MISSISSIPPIAN		KAYAK SHALE						(60 - 83 m) Mudstone: black, weathers black to light brown to rusty brown; finely laminated with siltstone, thin (< 2 cm) beds of fine-grained sandstone.	Anaerobic bottom conditions



Measured section 88A-56 Page 1 of 2
Section 8, T. 5 S, R. 38 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and T. Osterkamp

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE / GRAPHIC COLUMN	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN		ULUNGARAT	C	10, 20, 30, 40			(3 - 40 m) Chert pebble conglomerate and chert arenite: pebbles: light gray to black medium gray, weathers same with hematitic staining; clast supported at base, pebbly sandstone above 22 m; massive and horizontal cross-stratified conglomerate, trough cross-stratified pebbly sandstone. Upward decrease in grain size and scale of cross-stratification.	Fluvial system with associated flood-plain deposits.
							(0 - 3 m) Chert arenite: gray, weathers gray with some hematitic staining and pitting. Fining-upward interval.	
							Measured section begins at top of uppermost maroon siltstone.	

Measured section 88A-56 Page 2 of 2
Section 8, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and T. Osterkamp

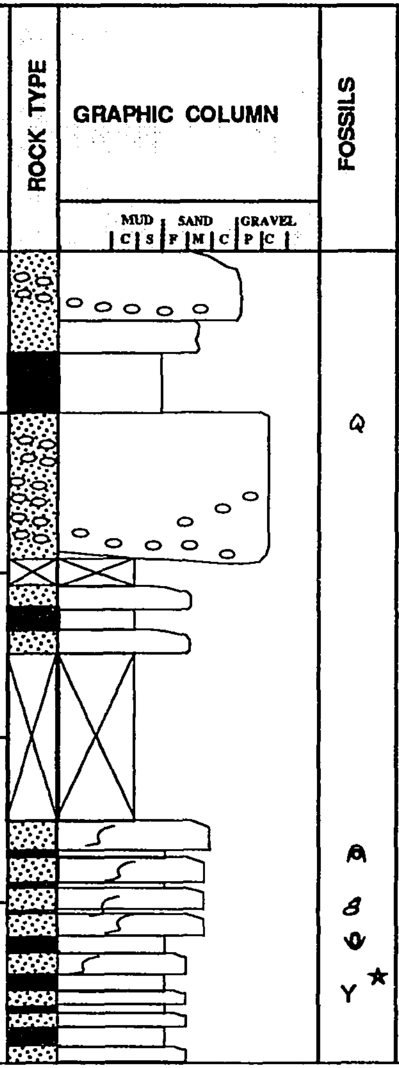
PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE / GRAPHIC COLUMN (MUD C S, SAND F M C, GRAVEL P C)	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN		ULUNGARAT	C	70, 60		ꝏ	Prominent topographic bench of black mudstone and siltstone with abundant plant fossils.	Fluvial system with associated flood-plain deposits
						ꝏ	(40 - 70 m) Chert arenite and chert granule to pebble conglomerate: gray, weathers same with hematitic staining and pitting. Fining-upward intervals in a thinning- and fining-upward succession.	

Measured section 89A-118

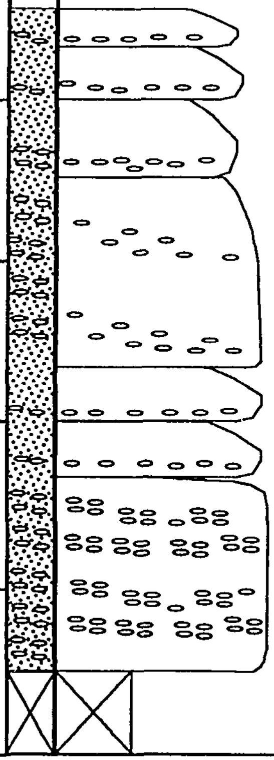
Section 16, T. 5 S., R. 37 E., Demarcation Point (A4) quadrangle, Alaska

Measured by A. Anderson and D. Stirling

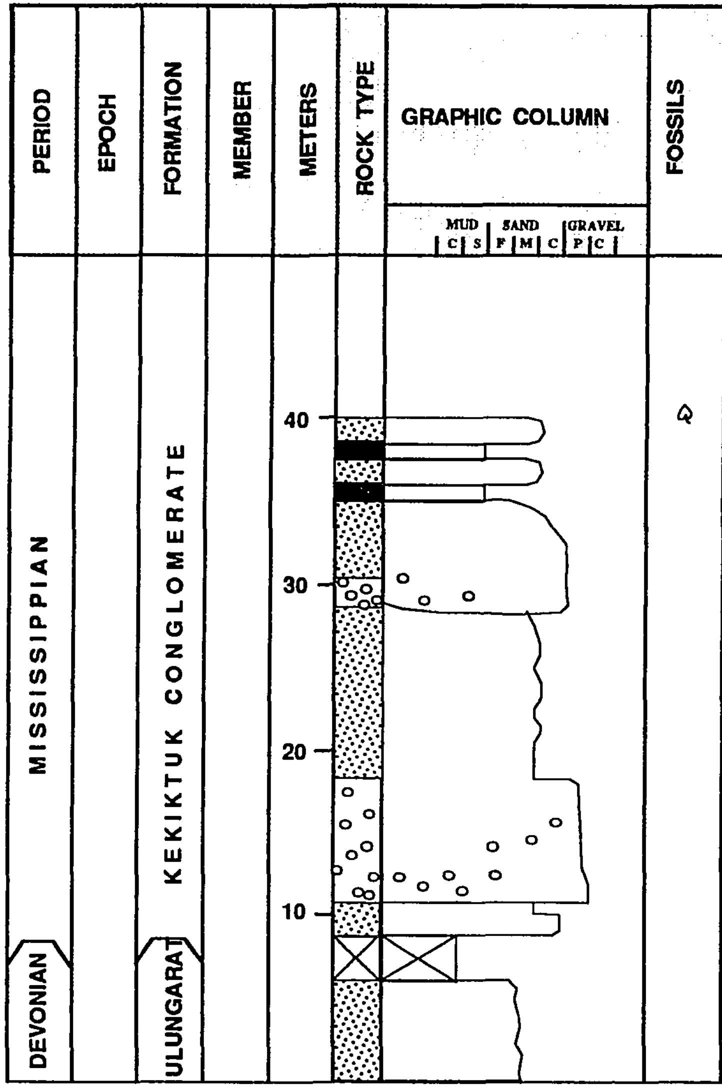
PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE / GRAPHIC COLUMN / FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN		ULUNGARAT FORMATION	B	40, 30, 20		(25 - 50 m) Chert arenite and chert and quartz pebble breccia to conglomerate: weathers orange-brown and maroon; size and angularity of clasts decreases upward. Chert arenite: medium- to fine-grained; some cross-stratification; series of fining-upward cycles with erosional bases.	Fluvial system with flood-plain deposits
			A	10		(0 - 14 m) Chert arenite and siltstone with thin-beds of mudstone: bioturbated; fining-upward cycles in an overall coarsening-upward succession. Base placed at lowermost in place outcrop above loose scree slope.	Shallow-marine



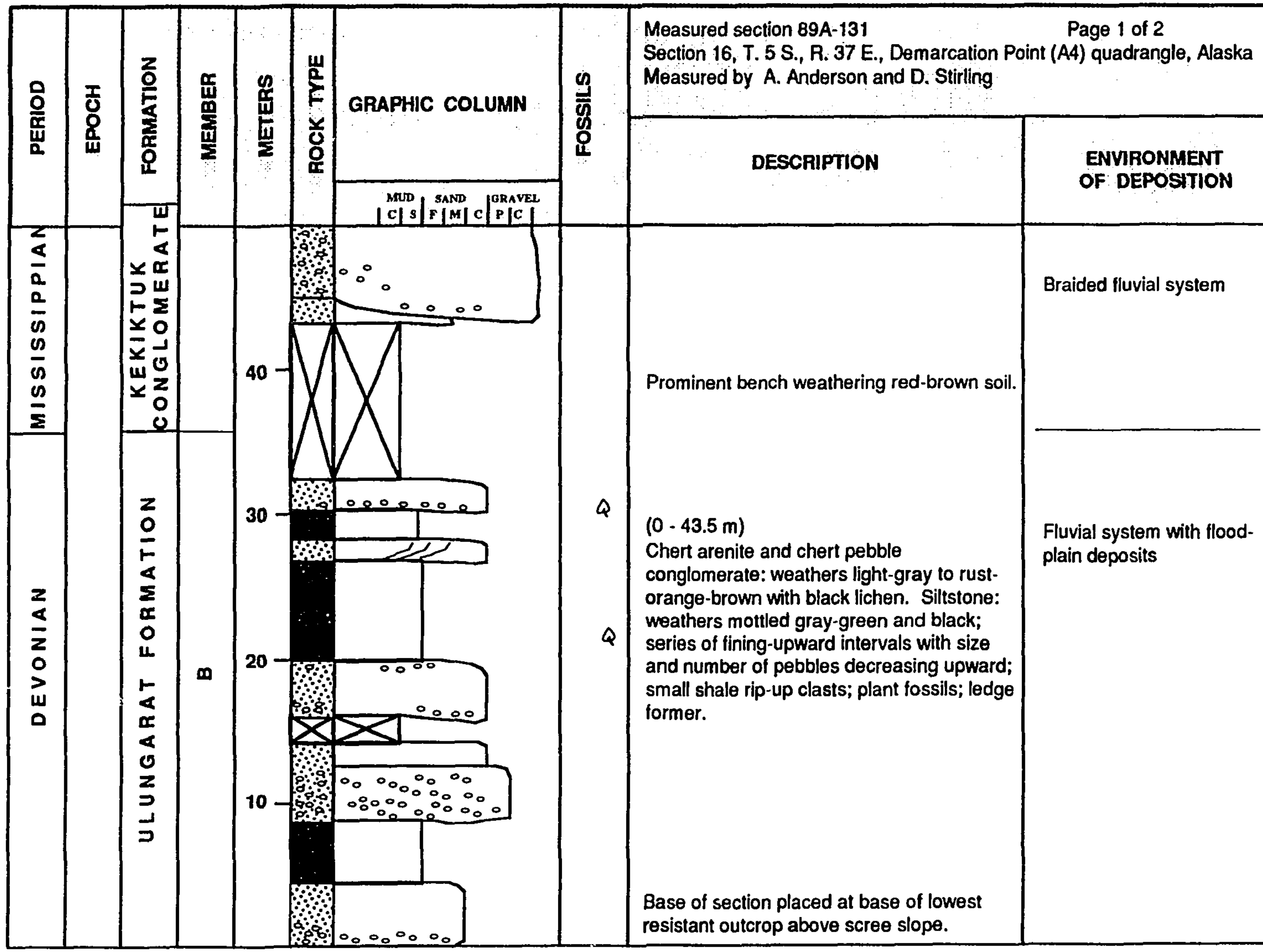
Measured section 89A-118 Page 2 of 2
Section 16, T. 5 S., R. 37 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and D. Stirling

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN (MUD C S; SAND F M C; GRAVEL P C)	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
MISSISSIPPIAN		KEKIKTUK CONGLOMERATE		90 80 70 60				Top of section placed at ridge crest. Upper surface undulates on 1 m wavelength, abruptly overlain by black mudstone, abundant plant fossils and burrows. (55 - 95 m) Chert pebble conglomerate and sandstone: light- to medium-gray with distinctive white beds near top of section; Conglomerate and sandstone cycles 2 to 3 m thick; internally each cycle begins with clast-supported, moderately sorted, chert pebble and cobble conglomerate. Conglomerate beds are massive to horizontally stratified and crudely fine upward; pebbles to 10 cm with 6 cm common. Medium-grained sandstone, tabular planar cross-stratification 2 m thick. Conglomerate is overlain by trough cross-stratified pebbly sandstone beds 8 to 10 cm thick. Top of each cycle consists of plane-bedded, fine-grained sandstone beds. Commonly only the lower conglomeratic part of each cycle is preserved beneath the conglomerate-filled erosional scour of the next overlying cycle. Upper 10 m of succession characterized by well-developed fining-upward cycles 0.5 to 2 m thick. Thin basal conglomerate is overlain by trough cross-stratified, medium- to fine-grained sandstone beds 20 to 50 cm thick. Top of each cycle is ripple cross-laminated and overlain by thin, organic-rich siltstone beds with plant fragments.	Braided fluvial system

Measured section 89A-129 Page 1 of 1
Section 16, T. 5 S., R. 37 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and D. Stirling



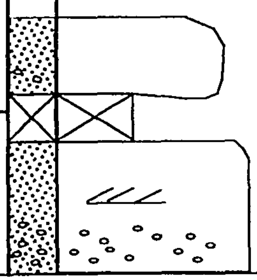
DESCRIPTION	ENVIRONMENT OF DEPOSITION
Top placed at top of cliff. Upper surface undulates on 1 m wavelength, abruptly overlain by black mudstone, abundant plant fossils.	
Chert pebble conglomerate and sandstone: round to sub-round pebbles to 3 cm diameter near base overlain by sandstone with chert pebbles < 1 cm in diameter. Sandstone is gray to lavender gray color. Multistory, amalgamated, clast-supported conglomerate, massive, horizontal, and trough cross-stratified with upward decrease in scale of cross-stratification and accompanying change from conglomerate to pebbly sandstone. Above basal conglomerate beds, medium-grained sandstone beds are trough and low-angle cross-stratified; fine-grained sandstone beds continue the fining-upward trend into horizontally stratified siltstone. Mudstone beds near top of the section contain plant fossils.	Braided fluvial system
Base placed at base of lowermost resistant outcrop at top of loose talus slope.	


Measured section 89A-131
Page 1 of 2
Section 16, T. 5 S., R. 37 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and D. Stirling
PERIOD
EPOCH
FORMATION
MEMBER
METERS
ROCK TYPE
GRAPHIC COLUMN
MUD
C
S
SAND
F
M
C
GRAVEL
P
C
FOSSILS
DESCRIPTION
ENVIRONMENT OF DEPOSITION
MISSISSIPPIAN
DEVONIAN
KEKIKTUK CONGLOMERATE
ULUNGARAT FORMATION
B
40
30
20
10
Braided fluvial system
Prominent bench weathering red-brown soil.
(0 - 43.5 m)
Chert arenite and chert pebble conglomerate: weathers light-gray to rust-orange-brown with black lichen. Siltstone: weathers mottled gray-green and black; series of fining-upward intervals with size and number of pebbles decreasing upward; small shale rip-up clasts; plant fossils; ledge former.
Fluvial system with flood-plain deposits
Base of section placed at base of lowest resistant outcrop above scree slope.

Measured section 89A-131 — Page 2 of 2

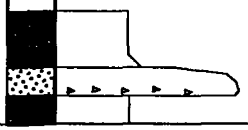
Section 16, T. 5 S., R. 37 E., Demarcation Point (A4) quadrangle, Alaska

Measured by A. Anderson and D. Stirling

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN (MUD: C, S; SAND: F, M, C; GRAVEL: P, C)	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
MISSISSIPPIAN		KEKIKTUK COMGLOMERATE		90, 80, 70, 60				Overlain by dip slope of blocky rubble; lithology similar to the 50 to 60 m interval. (43.5 - 66 m) Chert pebble to cobble conglomerate: white, gray, raspberry, and less common black pebbles and cobbles to 17 cm diameter; maximum clast size decreases upward to 9 cm diameter with 3 cm common; lowest interval is poorly sorted; horizontal and faint trough cross-stratified. Matrix and sandstone intervals: chert arenite, light-gray and lavender-gray; coarse- to medium-grained. Channelized fining-upward intervals with most of the finer-grained components of each channel eroded by the overlying channel. Sandstone beds overlie conglomerate along sharp contacts. Rapid upward fining and thinning of channels.	Braided fluvial system

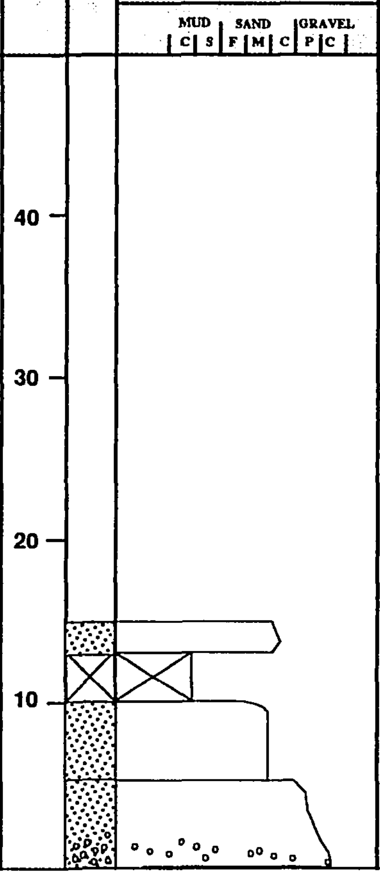
Measured section 90A-21 — Page 1 of 1
Section 35, T. 4 S., R. 37 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN (MUD: C, S; SAND: F, M, C; GRAVEL: P, C)	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
MISSISSIPPIAN		KAYAK SHALE		40, 30, 20				Measured only into lower Kayak Shale, patterns in grassy slope indicate large folds.	Colluvium (?)
				10				Mudstone, black, abundant plant fossils, feeding trace fossils.	
		KEKIKTUK CONGLOMERATE						(2 - 4.5 m) Sandstone and chert breccia, weathers medium-dark gray, matrix-supported, black chert breccia to 0.5 cm diameter.	
								(0 - 2 m) Mudstone, black	
								Base placed at top of massive chert of Or	

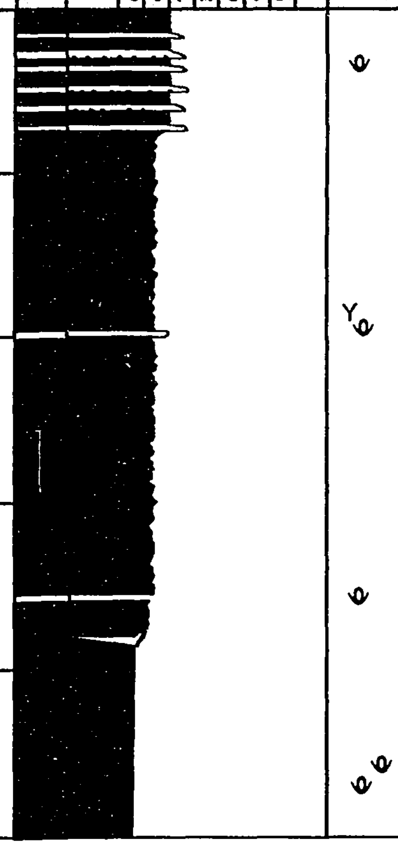


Measured section 90A-25 Page 1 of 1
Section 35, T. 4 S., R. 37 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
MISSISSIPPIAN								Overlain by grass covered interval weathering black mudstone and float of pebbly medium-grained sandstone.	
		KEKIKTUK CONGLOMERATE						(0 - 15 m) Chert pebble to cobble conglomerate: clast-supported; black, gray, and purple-raspberry colored pebbles and cobbles to 8 cm diameter; weathers light-gray, overlain by sandstone, no visible sedimentary structures. Base placed at top of bedded chert of Or.	Shallow channel (?)



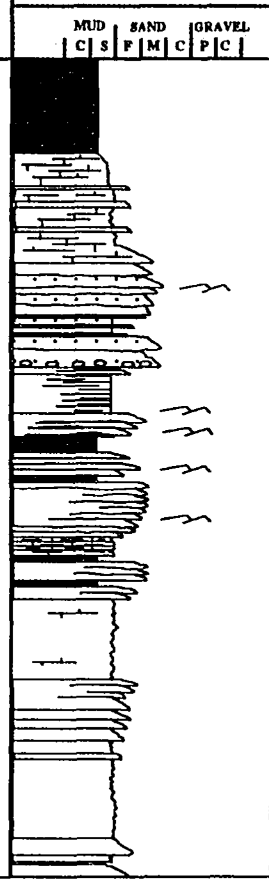
Measured section 90A-31 Page 1 of 8
Section 7, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN (MUD C S; SAND F M C; GRAVEL P C)	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN	EIFELIAN	ULUNGARAT FORMATION	A	40, 30, 20, 10				(14 - 43 m) Phyllite: black to dark gray, weathers medium-gray and yellow-brown. Uncommon, calcareous, fine-grained sandstone beds less than 6 cm thick.	Subaqueous delta plain
								(0 - 14 m) Mudstone: green gray, uncommon calcareous siltstone beds to 4 cm thick, contain broken brachiopod fossils. Age diagnostic brachiopods in the green-gray mudstone.	Upper delta slope
								Base of measured section placed at lowest exposure of green-gray mudstone.	

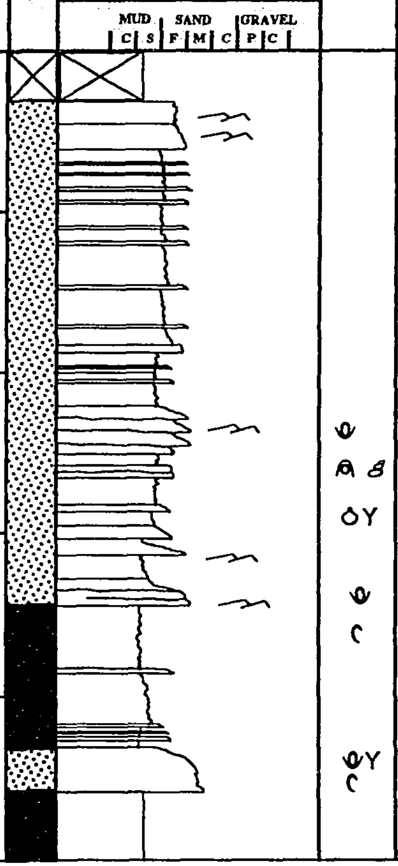
Measured section 90A-31 — Page 2 of 8

Section 7, T. 5 S., R. 38 E., Demarcation Poine (A4) quadrangle, Alaska

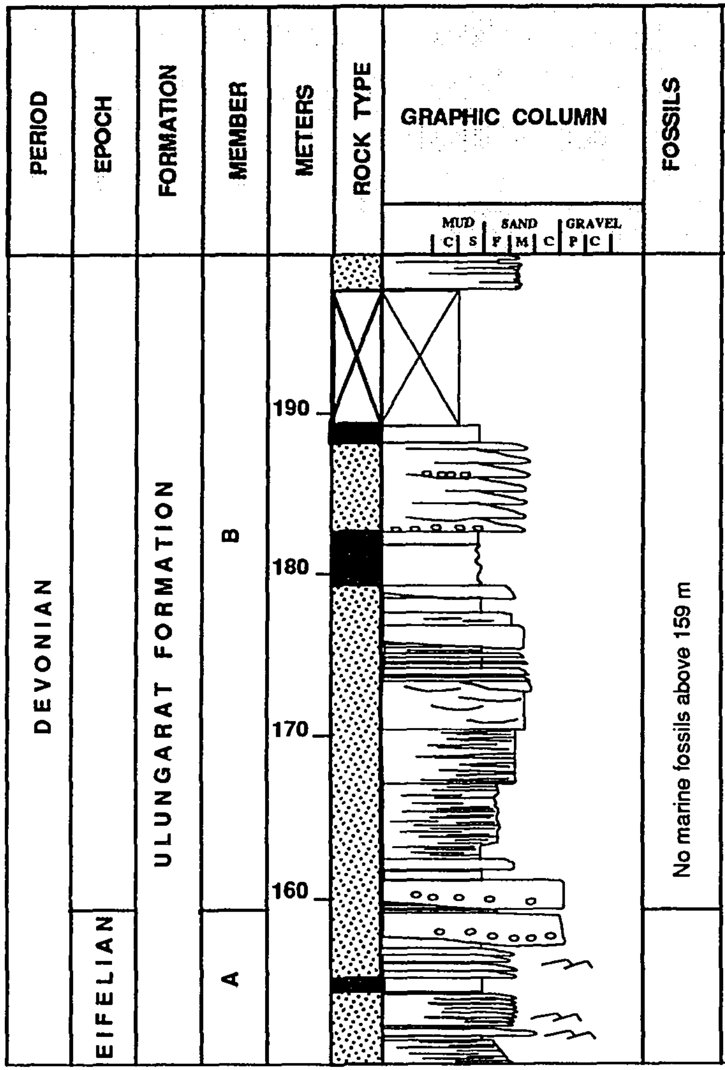
Measured by A. Anderson and Joe Clor

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN	EIFELIAN	ULUNGARAT FORMATION	A	90 80 70 60				(42 104 m) Siltstone with interbedded amalgamated sandstone intervals: Siltstone - weathers dark gray, bioturbated. Sandstone beds - weather dark gray and rusty brown; erosional bases with shale rip-up clasts, fossil debries, some ripple cross-lamination with mud drapes, individual beds generally 2 to 3 cm thick. Sandstone beds coarsen- and thicken-upward.	Upward shallowing marine setting. Subaqueous delta plain

Measured section 90A-31
Section 7, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

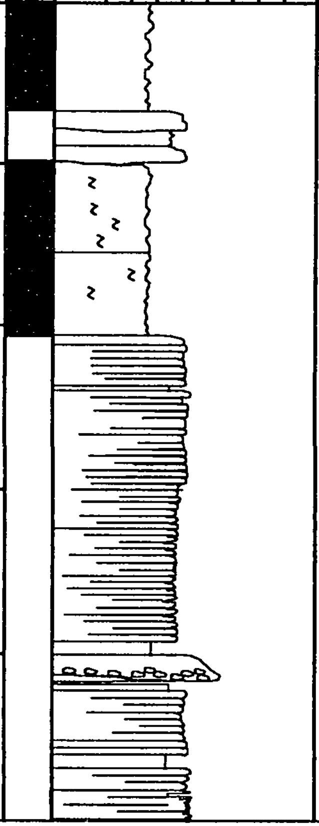
PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE / GRAPHIC COLUMN / FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN	EIFELIAN	ULUNGARAT FORMATION	A	140, 130, 120, 110		(104 - 159 m) Siltstone with amalgamated sandstone beds: sandstone beds - gray, weather gray, fine- to medium-grained, ripple cross-laminated, 2 to 4 cm thick, bioturbated, vertical burrows. Siltstone - medium-gray to black.	Subaqueous delta plain

Measured section 90A-31 Page 4 of 8
Section 7, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

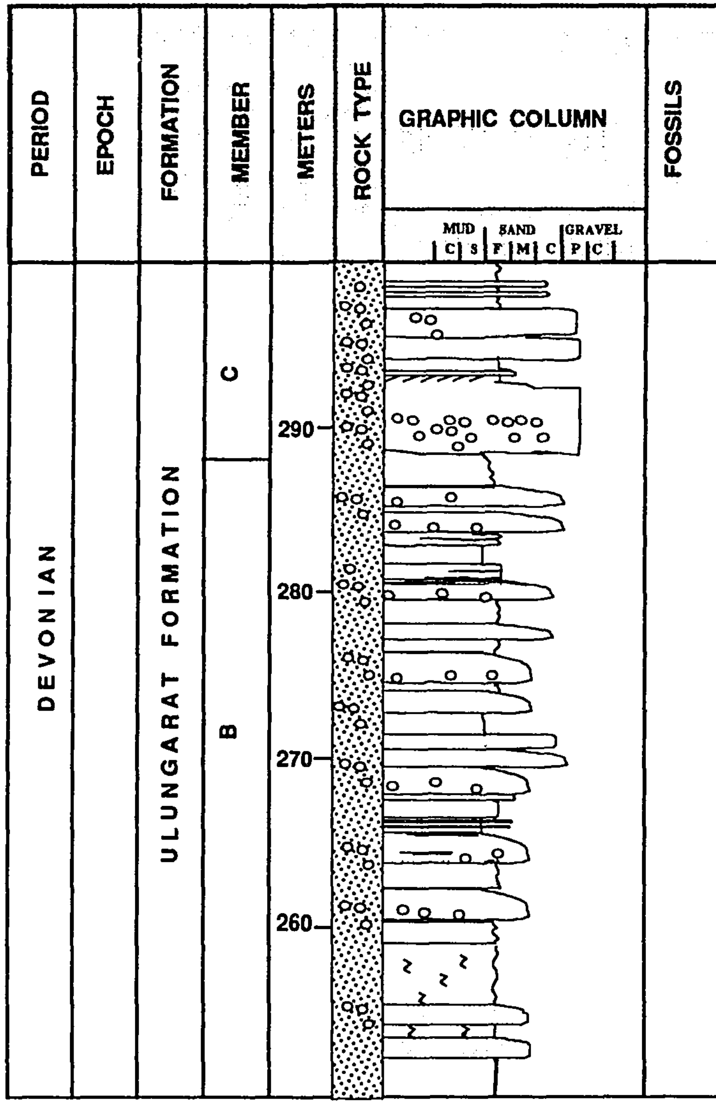


DESCRIPTION	ENVIRONMENT OF DEPOSITION
See description next page.	
Sharp contact of nonmarine rocks over rocks containing shallow-marine fossils.	
See description previous page.	

Measured section 90A-31
Section 7, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE / GRAPHIC COLUMN (MUD: C, S; SAND: F, M, C; GRAVEL: P, C)	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN		ULUNGARAT FORMATION	B	240 230 220 210			(159 - 288 m) Chert granule to pebble conglomerate, chert arenite, and siltstone: conglomerate is dominantly SA to SR, white and gray colored pebbles with some SA black pebbles; weathers medium-gray; individual fining-upward intervals are 1 to 3 m thick, trough and tabular planar cross-stratified, overlain by ripple cross-laminated sandstone and horizontal laminated siltstone. Interbedded rose-red mudstone with green-gray mottling, mud cracks, and root casts. Intervals of stacked, medium- to fine-grained sandstone beds. Individual beds 2 to 18 cm thick, erosional bases, fine-upward, and ripple cross-laminated at the top. Local trough cross-stratified sandstone beds 5 to 10 cm thick. The succession is organized as fining-upward intervals in an overall coarsening-upward succession; lower half of the succession is dominated by fine-grained deposits. Upper half has less mudstone and consists of 70 to 80% channel-fill deposits.	Sand-rich fluvial system with flood plain, levee, and crevasse splay deposits.

Measured section 90A-31 Page 6 of 8
Section 7, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

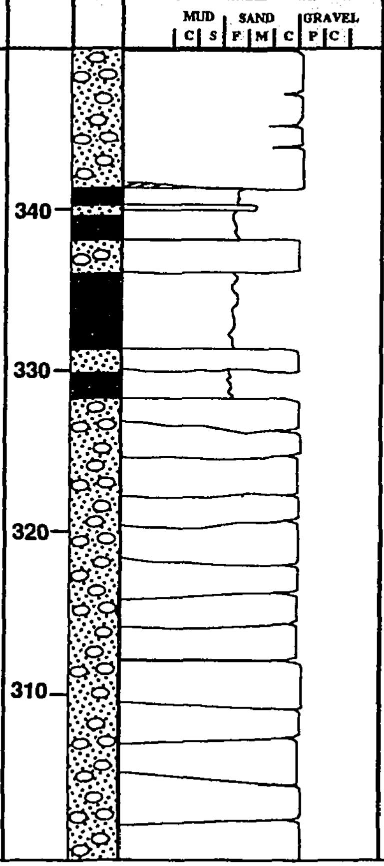


DESCRIPTION	ENVIRONMENT OF DEPOSITION
See description next page.	
See description previous page.	

Measured section 90A-31

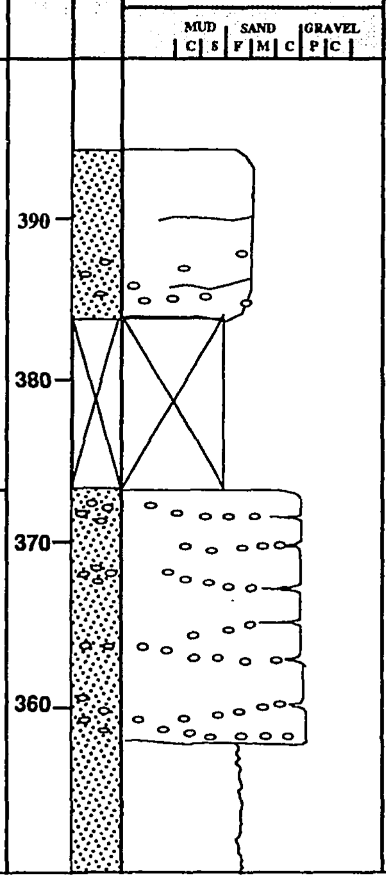
Section 7, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska

Measured by A. Anderson and J. Clor

PERIOD	EPOCH	FORMATION	MEMBER	METERS / ROCK TYPE / GRAPHIC COLUMN	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN		ULUNGARAT FORMATION	C			(288 - 373 m) Chert pebble to cobble conglomerate and chert arenite: dominantly subangular to subrounded white and gray colored clasts with some subangular black clasts; gray to light gray, weathers gray with hematite and limonite staining; poorly sorted, clast-supported conglomerate, massive to horizontally stratified, in places faintly trough cross-stratified, crudely fines upward. Multiple channel-fill successions with erosional bases. Stratification within channel-fill varies upsection from trough to tabular planar sets and cosets arranged in upward-thinning and -fining cycles. Some tabular cross-stratification present beneath the erosional base of one channel. Pebbly sandstone beds 8 to 15 cm thick are trough cross-stratified; forms cliffs. Mudstone and sandstone: red-brown with green-gray mottling; recessive weathering intervals. Sandstone beds, 10 to 60 cm thick, erosional base, ripple cross-laminated present on upper surface; beds extend laterally across outcrop exposures. Mudstones and thin sandstone beds underlie, are lateral to, and overlie the thick conglomeratic succession.	Amalgamated braided fluvial system and flood plain deposits.

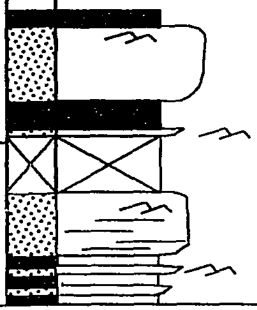
Measured section 90A-31
Section 7, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE / GRAPHIC COLUMN	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN		ULUNGARAT FORMATION					Top of section is prominent bench overlain by recessive weathering black mudstone.	
			D	390			(384 - 394 m) Pebbly sandstone: chert pebbles, medium- to fine-grained chert arenite.	Fluvial system and flood-plain deposits.
				380			(373 - 384 m) Covered	
			C	370, 360				

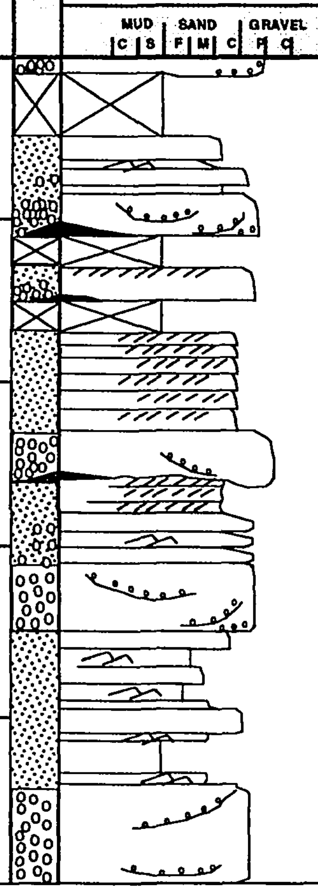


Measured section 90A-66 Page 1 of 1
Section 24, T. 5 S., R. 37 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and D. Stirling

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN (MUD C S; SAND F M C; GRAVEL P C)	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
MISSISSIPPIAN		KAYAK SHALE		40				(12 - 15) Sandstone: weathers medium-light gray and orange-tan, lichen cover obscures sedimentary structures; interval has sharp lower and upper contacts. Megaripples 1 m in wavelength on upper surface.	Marginal marine sandstone, possibly a distributary mouth bar.
				30				(6 - 10 m) Covered	
				20				(2 - 6 and 10 - 12 m) Sandstone: weathers gray, fine-grained, beds 0.5 to 2 cm thick with sharp lower and upper contacts, bioturbated.	
				10				(0 - 2 m) Siltstone with interbedded fine-grained sandstone beds 2 to 3 cm thick; bioturbated. Sandstone beds coarsen- and thicken-upward, medium-to fine-grained, beds 2 to 6 cm thick; ripple cross-lamination; sharp lower contact.	
								Based placed at lowest resistant outcrop overlying dip slope of Kekiktuk Conglomerate. Measured section underlain by an estimated 10 m of black mudstone with plant fossils.	

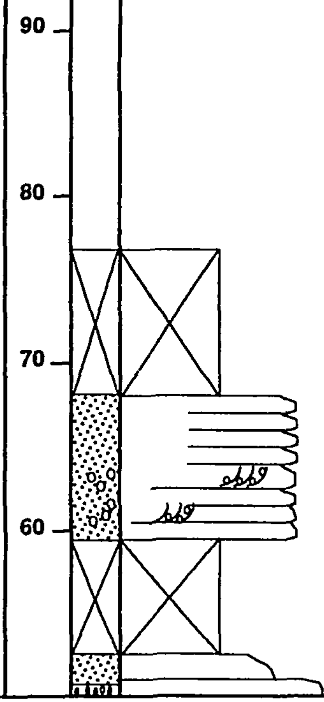


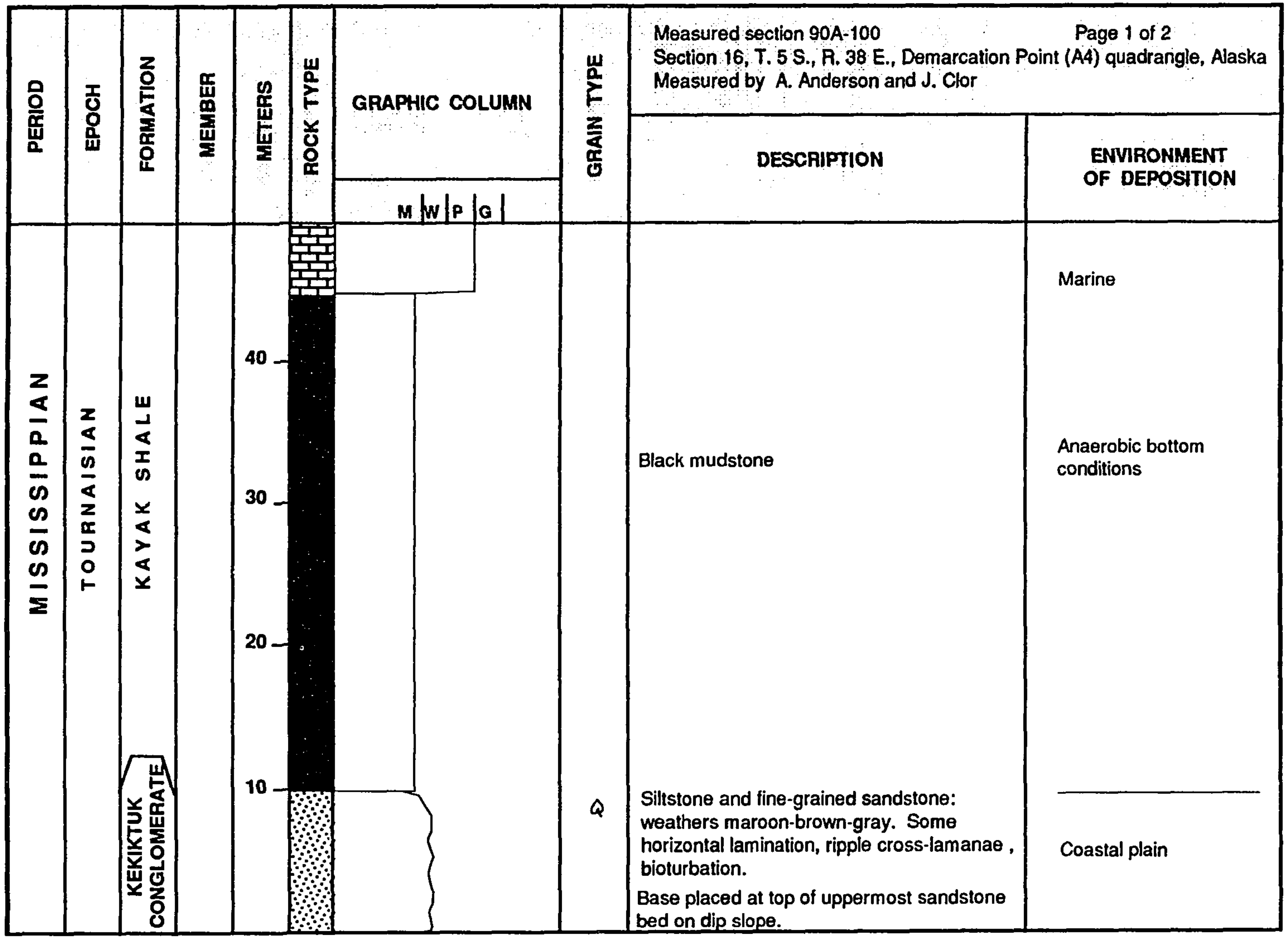
Measured section 90A-93
Section 14, T. 5 S., R. 37 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE / GRAPHIC COLUMN	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN		ULUNGARAT	B	40 30 20 10			(0 - 52.5 m) Well-developed fining-upward intervals of chert pebble conglomerate and chert arenite: channel-fill of gray and black chert pebbles average 1 cm in diameter, as large as 5 cm; SA-SR; generally grade upward to pebbly sandstone; clast to matrix supported; some trough cross-stratification visible. Stacked channel successions with individual channels 0.5 to 1 m thick; erosional bases with some preservation of underlying fine-grained deposits. At 24 m overlying channel is erosional to a depth of 1 m into the underlying fine-grained sediments. Channel-fill successions grade laterally into and are overlain by tabular planar cross-stratified sandstone. Covered intervals weather float of fine-grained sandstone - siltstone. Base of section placed at northernmost resistant outcrop on east side of drainage. Stratigraphically below is loose slope of siltstone float containing abundant marine invertebrate fossils.	Fluvial system and flood-plain deposits

Measured section 90A-93
Section 15, T. 5 S., R. 37 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

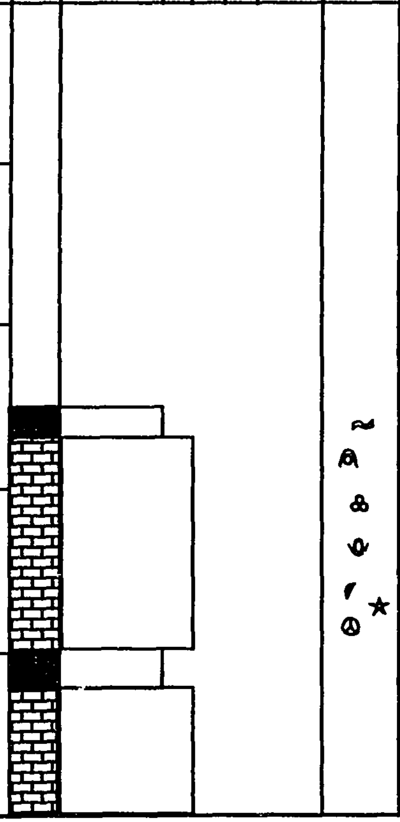
PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN (MUD: C, S; SAND: F, M, C; GRAVEL: P, C)	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN		ULUNGARAT	B					Covered slope (12 m) to base of overlying unit of chert conglomerate: gray and raspberry colored chert pebbles and cobbles to 7 cm diameter; clast supported. Interpreted to be Kekiktuk Conglomerate.	
								(59.5 - 68 m) Pebbly chert arenite: 95% black lichen cover. Trough cross-stratified beds to 0.5 m. Medium-grained sandstone beds 10 - 20 cm thick, possible tabular planar cross-stratification.	Fluvial system and flood-plain deposits
								(52.5 - 59.5 m) Blocky rubble: upper 2.5 m weathers fine-grained sandstone - siltstone. Laterally fining upward interval as below.	




Measured section 90A-100
Page 1 of 2
Section 16, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor
PERIOD
EPOCH
FORMATION
MEMBER
METERS
ROCK TYPE
GRAPHIC COLUMN
M W P G
GRAIN TYPE
DESCRIPTION
ENVIRONMENT OF DEPOSITION
MISSISSIPPIAN
TOURNAISIAN
KAYAK SHALE
KEKIKTUK CONGLOMERATE
40
30
20
10
Marine
Black mudstone
Anaerobic bottom conditions
Siltstone and fine-grained sandstone: weathers maroon-brown-gray. Some horizontal lamination, ripple cross-lamanae , bioturbation.
Base placed at top of uppermost sandstone bed on dip slope.
Coastal plain

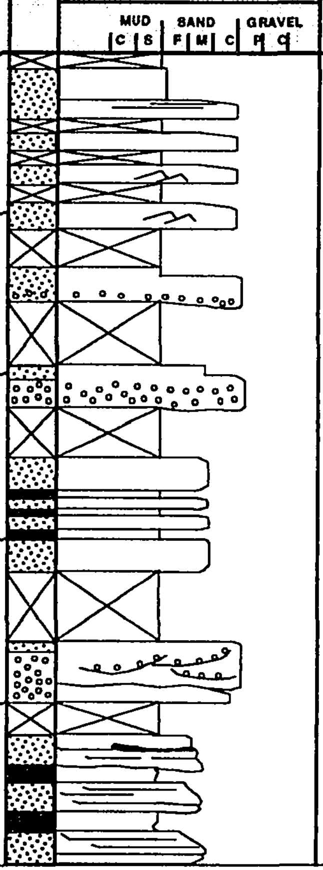
Measured section 90A-100
Section 16, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN (M W P G)	GRAIN TYPE	DESCRIPTION	ENVIRONMENT OF DEPOSITION
MISSISSIPPIAN	TOURNAISIAN	KAYAK SHALE		90 80				Top of section placed at top of cliff. Dip slope weathers black mudstone with uncommon light gray weathering limestone beds.	Marine Shallow-water near or within the photic zone.
				70 60				Argillaceous crinoidal packstone interbedded with lime mudstone: Packstone beds 1 to 2 cm thick, have erosive bases, contain fossil fragments, and ripple cross-laminae at the top. Packstone/mudstone ratio increases upsection. Packstone beds record transportation by traction currents and deposition by waning flow.	

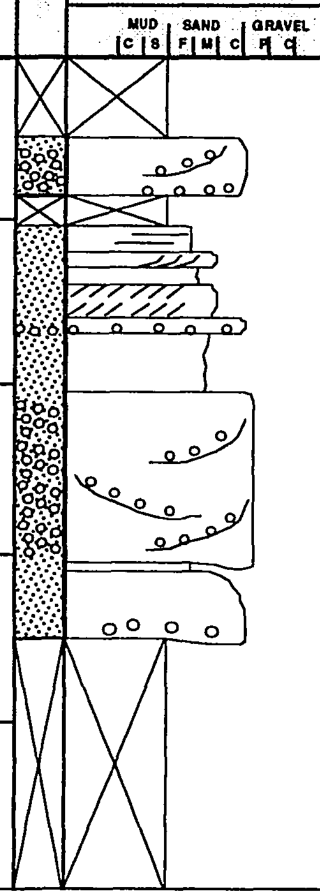


Measured section 90A-112
Section 11, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

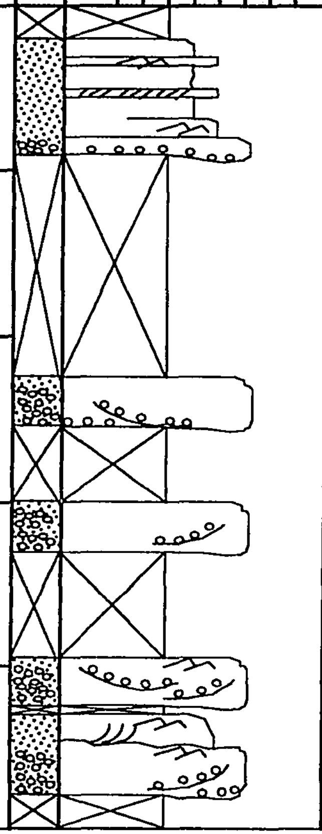
PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN		ULUNGARAT	B	40, 30, 20				(10 - 48 m) Chert pebble conglomerate and chert arenite alternate with covered mudstone intervals: conglomeratic intervals are gray, weathering dark gray and maroon-orange with black lichen; black and gray pebbles to 3 cm diameter; multiple channel-fills with erosional bases; locally trough cross-stratified sandstone beds; beds 4 - 10 cm thick; ripple cross-lamination, intervals fine-upward; Sandstone/mudstone ratio approximately equal. (0 - 10 m) Chert arenite: upward thinning beds from 15 cm to 1 - 3 cm thick; laterally individual beds thicken and thin; mudstone-siltstone intervals contain thin (1 - 2 cm) ripple cross-laminated, fine-grained sandstone.	Fluvial system with associated flood-plain deposits
			A	10				Base of section placed at northernmost exposure of competent rock. Stratigraphically below is platy siltstone-mudstone weathering from slope.	Upper shoreface



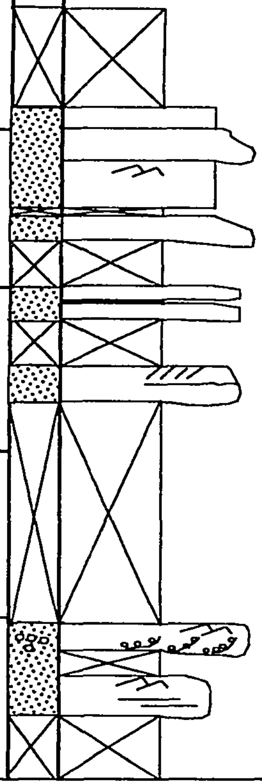
Measured section 90A-112 — Page 2 of 4
Section 11, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN		ULUNGARAT	B	90, 80, 70, 60				(95 - 102 m) Covered with large talus blocks of conglomerate and coarse-grained sandstone. Laterally see likely channel interval. (65 - 95 m) Chert pebble conglomerate and chert arenite: gray to medium-gray; pebbles to 3 cm diameter are common. Conglomerate abruptly overlain by medium- to fine-grained sandstone. (48 to 65 m) Covered with moss and low brush. Laterally see fining-upward intervals as below.	Fluvial system with associated flood-plain deposits

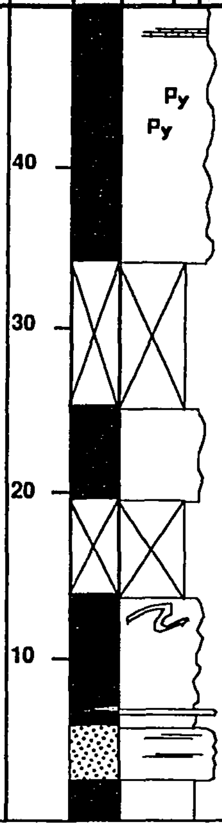
Measured section 90A-112 Page 3 of 4
Section 11, T. 5 S., R. 38 E., Demarcation Point (A-4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN (MUD C S; SAND F M C; GRAVEL F C)	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN		ULUNGARAT	B	140, 130, 120, 110				(141 - 157 m) Chert pebble conglomerate and chert arenite conglomeratic channel-fill: pebbles to 3 cm diameter, 1 cm common; dominantly gray chert; conglomerate is poorly sorted with coarse-grained sandstone to grit matrix. Above 142 m, channels are overlain by medium-grained sandstone, beds 2-10 cm thick, and ripple cross-laminated; tabular planar cross-sets. These are interbedded and laterally interfinger with fine-grained sandstone and siltstone with mudcracks. (102 - 141 m) Chert pebble conglomerate: gray, white, rare black color clasts; pebbles to 4 cm, 1 cm common; poorly sorted, crude fining-upward; several channels erosional into lower channels; pebble size decreases and sandstone/conglomerate ratio increases upward in each cycle. Upper 30 cm of each interval fines upward from coarse- to medium-grained sandstone and siltstone with ripple cross-stratification at the top. Each cycle is overlain by a covered interval of finer grained deposits. Covered intervals are vegetation covered fine-grained deposits	High sinuosity fluvial system and flood-plain deposits

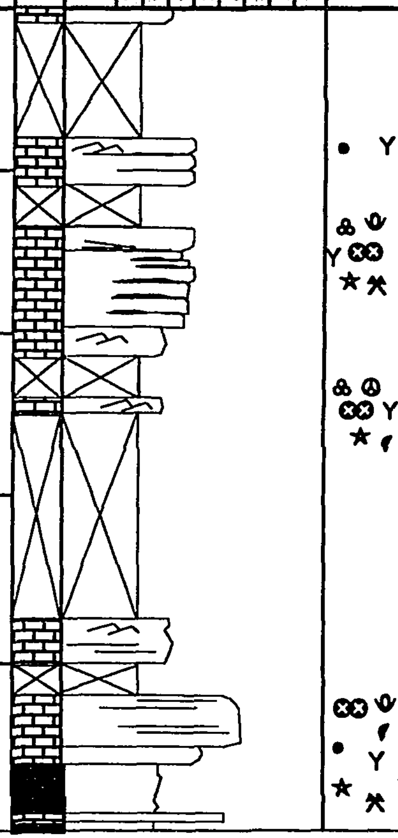
Measured section 90A-112 — Page 4 of 4
Section 11, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN (MUD C S; SAND F M C; GRAVEL F C)	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
DEVONIAN		ULUNGARAT	B	160–190				Top of measured section is top of ridge On dip slope: stacked, fining upward intervals of chert-quartz pebble conglomerate and sandstone. (183 - 191.5 m) Two fining-upward intervals: each begins with clast-supported chert-pebble conglomerate. Above 188 m 80% of pebbles are subangular. Conglomerate abruptly overlain by medium-grained sandstone, beds 4-15 cm thick; some ripple cross-stratification; interbedded and interfinger with coarse-grained sandstone containing black chert grit. (173 - 183 m) Pebbly chert arenite: beds 15 - 40 cm thick; angular chert pebbles < 0.5 cm diameter; some tabular cross-stratification 4 cm high. (157 - 173 m) Chert pebble conglomerate: pebbles are light gray, rare black color; trough cross-stratification defined by fining to medium-grained sandstone; upper 6 - 10 cm is medium-grained sandstone with ripple cross-stratification.	Fluvial system, covered intervals are fine-grained, probably record flood plain deposition.

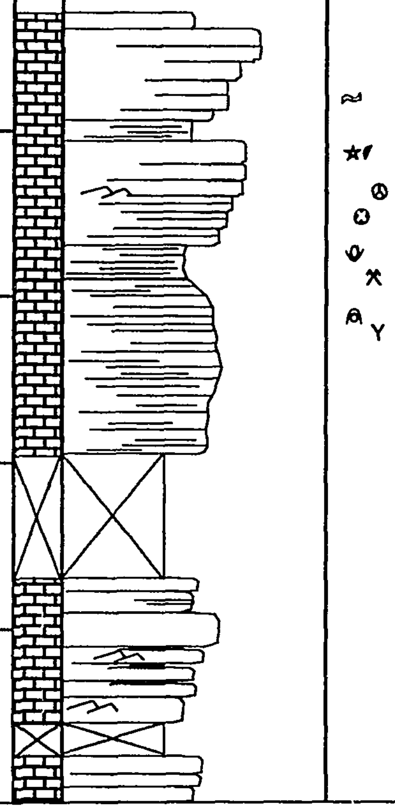
Measured section 90A-130
Section 22, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

PERIOD	EPOCH	FORMATION	MEMBER	METERS / ROCK TYPE / GRAPHIC COLUMN (MUD C S, SAND F M C, GRAVEL F C)	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
EARLY MISSISSIPPIAN	LATE VISEAN	KAYAK SHALE				(0 - 50.5 m) Mudstone - siltstone: dark gray to black, fissile. Above 44 m - infrequent, laterally discontinuous (1-2 m) iron stone concreation beds (4 - 6 cm thick). Some thin (1 - 2 cm) limestone beds. 10.5 - 13.5 m - float of small fold hinges indicate structural disruption. No apparent duplication of section. 2.5 - 5.5 m - fine-grained sandstone, weathers dark maroon, thin-bedded (1 - 2 cm), horizontal bedded. Base of measured section placed at northernmost resistant outcrop along west side of the stream. The section is stratigraphically above a loose slope of black mudstone. Due to brush and the incompetent nature of the rock, it is not possible to determine possible structural disruption below this point.	Open marine Anaerobic bottom conditions

Measured section 90A-130 Page 2 of 3
Section 22, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

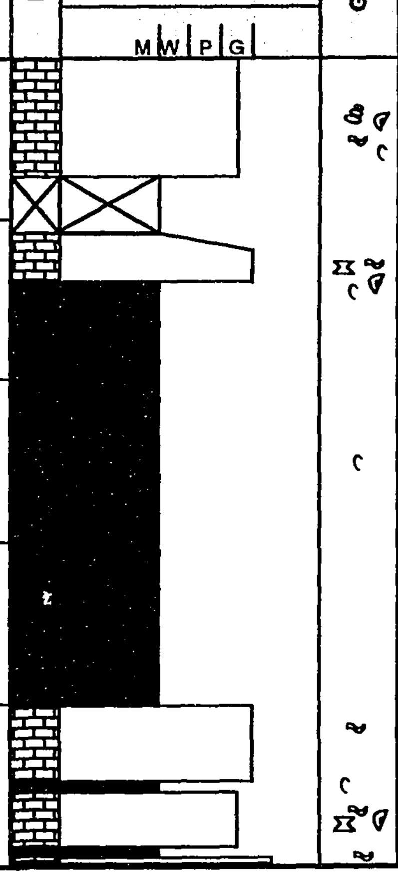
PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE / GRAPHIC COLUMN (MUD C S; SAND F M C; GRAVEL F C)	FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
MISSISSIPPIAN	LATE VISEAN	KAYAK SHALE		90 80 70 60			(54 - 120.5 m) Argillaceous skeletal packstone intervals alternate with argillaceous skeletal mudstone intervals:. Argillaceous skeletal packstone: Gray, weathers dark to medium gray. Broken and abraded pelmatozoan and bryozoan dominate; abundant ostacods, forams, calispheres, sponge spicules, alga, trilobites, and brachiopods. Trilobite and brachiopod shells often show borings. Intact shells filled with sparite. Above 100 m is peloidal. Coral bondstone at 75.5 m. Thickening upward intervals; thin to medium bedded (2- 5 cm thick), sharp lower and upper contacts; horizontal and ripple cross-lamination; grit size fossils at distinct horizons within beds, elsewhere fossils are disseminated throughout the bed; low-angle cross-stratification at 85 m; Nodular black cherts (3 - 4 cm diameter); below 125 m chert is preferentially developed in fine-grained intervals. Abundant dead oil. Argillaceous lime mudstone: Covered intervals and fine-grained intervals between packstone beds; in places platy; very calcareous. Upsection bioclastic beds become thicker and more prominent; lime mudstone intervals become thinner. Recessive weathering.	Restricted marine
							(50.5 - 54 m) Pelmatozoan Bryozoan packstone with large intact brachiopods: Syringaporid, sponge spicules, ostracods, coral; dead oil; weathers limonitic; thin-bedded (1 - 3 cm); ironstone concreations with clusters of pyrite cubes at center; stylolites.	Open marine

Measured section 90A-130 Page 3 of 3
Section 22, T. 5 S., R. 38 E., Demarcation Point (A4) quadrangle, Alaska
Measured by A. Anderson and J. Clor

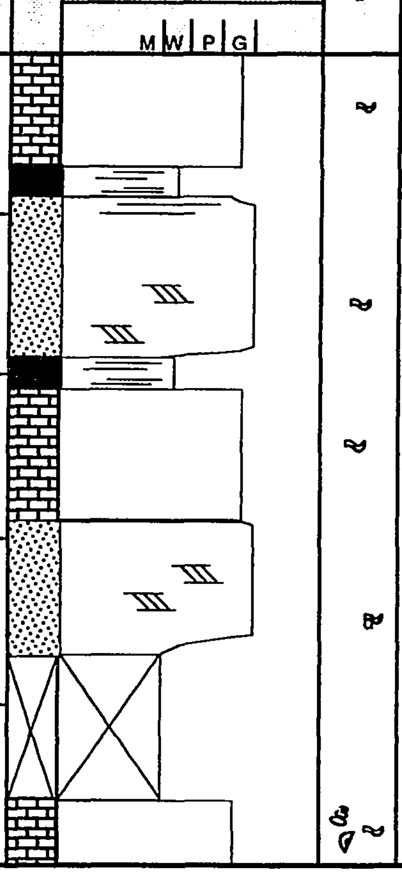
PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE / GRAPHIC COLUMN (MUD C S; SAND F M C; GRAVEL P C) / FOSSILS	DESCRIPTION	ENVIRONMENT OF DEPOSITION
MISSISSIPPIAN	VISEAN	LISBURNE LIMESTONE		140, 130, 120		(120.5 - 146 m) Pervasive black chert replacement of bioclastic packstone: Abraded shell fragments; styolites truncate shells. Dead oil. Thickening upward intervals with sharp lower and upper contacts.	Restricted marine
		KAYAK SHALE		110		Gradational contact: The top of the Kayak Shale is arbitarily placed at the uppermost black mudstone interval < 5 m thick which is coincident with the base of the lowermost thick limestone interval.	

Measured section 91A-21 | Page 1 of 3
Section 8, T. 5 S., R. 38 E., Demarcation (A-4) quadrangle, Alaska
Measured by A. Anderson

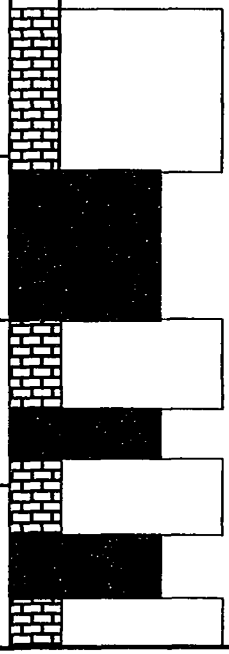
PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN (M W P G)	GRAIN TYPES	DESCRIPTION	ENVIRONMENT OF DEPOSITION
LATE DEVONIAN and/or EARLY MISSISSIPPIAN		MANGAQTAAQ		40, 30, 20, 10				(36 - 54 m) Skeletal algal grainstone-packstone: Ostracod and gastropod fragments, black intraclasts; faint cross-stratification(?); weathers black and orange-black; forms ledges.	Shallow water shore complex
								(10 - 36 m) Mudstone and wackestone with minor skeletal debris.	Anaerobic bottom conditions Deeper water
								(0 - 10 m) Algal packstone to grainstone overlain by mudstone with minor skeletal debris in 3 intervals: Basal 0.5 m is algal boundstone. Algae, ostracods, black intraclasts. Oncoids from <0.5 to 7 cm across; bedding(?) 4 to 10 cm thick; sharp, irregular contacts; mudstone between some beds; black cubic areas at center of several "clotted" algae; forms ledges.	Shallow water shore complex
								Below measured section: Black shale with thin limestone beds (<2 cm thick); Lime mudstone with black intraclasts and < 20% skeletal fragments; some faint cross-stratification.	



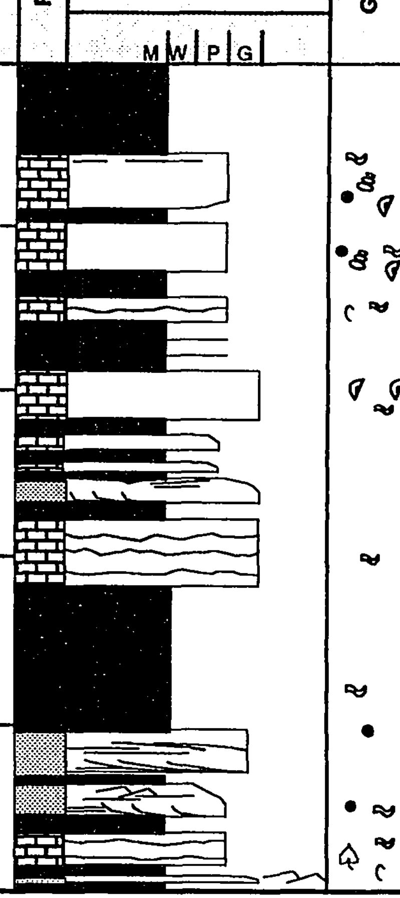
Measured section 91A-21 Page 2 of 3
Section 8, T. 5 S., R. 38 E, Demarcation Point (A-4) quadrangle, Alaska
Measured by A. Anderson

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE / GRAPHIC COLUMN / GRAIN TYPE	DESCRIPTION	ENVIRONMENT OF DEPOSITION
LATE DEVONIAN - EARLY MISSISSIPPIAN		MANGAQTAAQ		90, 80, 70, 60		(63 - 71 m) and (79 - 93 m) Sandstone and siltstone: chert arenite with algal intraclasts; weathers medium-gray and orange-brown. Sedimentary structures obscured by weathered surface. Float with tabular planar cross-stratification. Forms ledges. Black, platy siltstone; recessive weathering. (71 - 79 m) Algal grainstone to packstone: prominent oncoids on bedding surfaces. Weathers black and orange-black; alternates with black mudstone. Forms ledges.	Shallow water shore complex alternated with black mudstone intervals interpreted to record deeper water deposition.

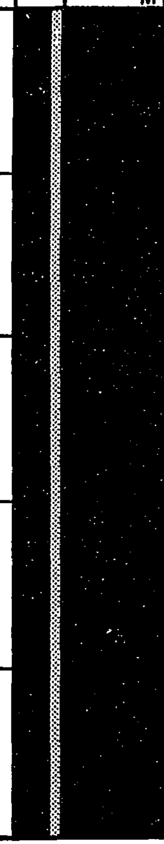
Measured section 91A-21 Page 3 of 3
Section 8, T. 5 S., R. 38 E, Demarcation Point (A-4) quadrangle, Alaska
Measured by A. Anderson

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE / GRAPHIC COLUMN (M W P G)	GRAIN TYPE	DESCRIPTION	ENVIRONMENT OF DEPOSITION
LATE DEVONIAN and/or EARLY MISSISSIPPIAN		MANGAQTAAQ		140 130 120 110			Above measured section: ledges of sandstone and small pebble conglomerate. Float includes some algal limestone indicating limestone interbeds (93-139 m) Algal grainstone-packstone: resistant outcrops 3 - 4 m thick, laterally and vertically separated by loose slope. Limestone weathers black and orange-brown.	Algal limestone alternates with black mudstone interpreted to record alternating shallow water shore complex and deeper water.

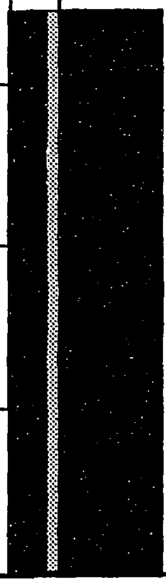
Measured section 91A-27 Page 1 of 3
Section 9, T. 5 S., R. 38 E, Demarcation Point (A-4) quadrangle, Alaska
Measured by A. Anderson

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE / GRAPHIC COLUMN (M W P G) / GRAIN TYPE	DESCRIPTION	ENVIRONMENT OF DEPOSITION
LATE DEVONIAN and/or EARLY MISSISSIPPIAN		MANGAQTAAQ		40 30 20 10		(37 - 44.5 m) Algal packstone with peloidal packstone between algal areas; ostracods, gastropods. (23 - 37 m) Argillaceous skeletal algal packstone in places oncolitic; alternates with black mudstone. Forms ledges. (1 - 4.5 m) and (9 - 23 m) Skeletal algal grainstone to packstone in places peloidal: ostracods, gastropods; sharp contacts with mudstone interbeds; oncoids prominent; 1 large (30 cm across) algal structure draped with mud; mudcracks. Forms ledges. (4.5 - 9 m) Sandstone: mixed chert arenite and carbonate grains. In places trough cross-stratified with erosional bases to 1.5 m depth; tabular planar cross-stratification and ripple cross-lamination. Forms ledges. Interbedded black mudstone: sharp contact with over and underlying sandstone and/or limestone lithofacies. (0 - 1 m) Sandstone and interbedded mudstone: chert arenite with skeletal fragments and carbonate grains; beds 1 - 2 cm thick; low-angle cross-stratification with mud drapes; interbedded mudstone with abundant plant fossils. Measured section underlain by black siltstone with abundant plant fossils. Lower contact is covered.	Alternating algal limestone and black mudstone Interpreted to be alternating algal flat shore complex and deeper water. Sandstone beds as channelized and unchannelized deposits.

Measured section 91A-27 Page 2 of 3
Section 9, T. 5 S., R. 38 E., Demarcation Point (A-4) quadrangle, Alaska
Measured by A. Anderson

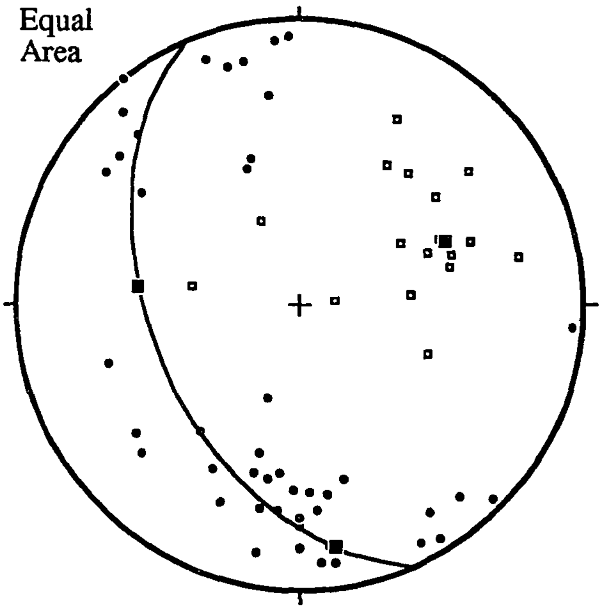
PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN M W P G	GRAIN TYPE	DESCRIPTION	ENVIRONMENT OF DEPOSITION
LATE DEVONIAN and/or EARLY MISSISSIPPIAN		MANGAQTAAQ		90 80 70 60				(44.5 - 128 m) Mudstone-siltstone: Black, calcareous, fissile; interbedded on scale of 2-4 mms. Sharp basal contact; upper contact covered.	Anaerobic bottom conditions

Measured section 91A-27
Section 9, T. 5 S., R. 38 E., Demarcation Point (A-4) quadrangle, Alaska
Measured by A. Anderson

PERIOD	EPOCH	FORMATION	MEMBER	METERS	ROCK TYPE	GRAPHIC COLUMN (M W P G)	GRAIN TYPE	DESCRIPTION	ENVIRONMENT OF DEPOSITION
LATE DEVONIAN - EARLY MISSISSIPPIAN		MANGAQTAAQ		140, 130, 120, 110				Upper contact is covered by approximately 20 m of vegetation and loose talus. Overlying conglomerate and sandstone beds interpreted to be Kekiktuk Conglomerate.	Anaerobic bottom conditions

APPENDIX I. EQUAL-AREA STEROGRAPHIC PROJECTIONS

(A) Romanzof Chert



Location I

D2 Fold

So = 45
FH = 17

BFGC = 157, 47 W
FA = 67, 43

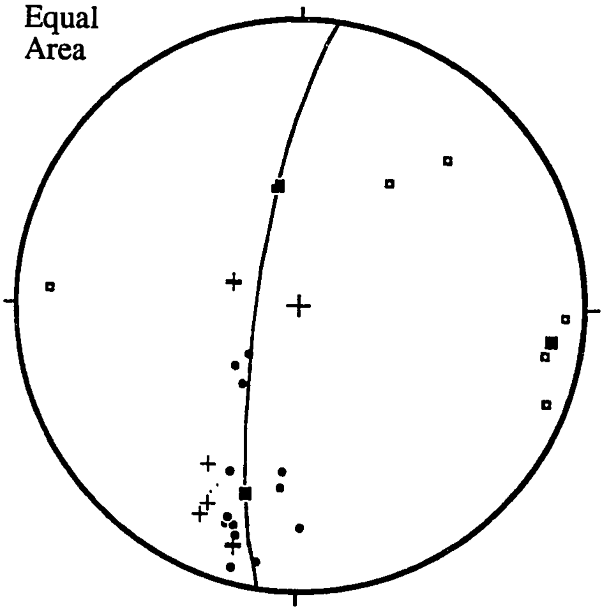
KEY

- Pole of Bedding, So
- Fold Hinge, FH
- Pole of Fold Axial surface, AS
- Best Fit Great Circle,BFGC
- Pole of Great Circle = Fold Axis, FA

Appendix I. Equal-area sterographic projections of poles to planes for mesoscopic structures and trend and plunge of fold hinges. D1 and D2 are pre-Middle Devonian events and D3 and D4 are Cretaceous(?) to Cenozoic events. Folds in the Romanzof cherts (A-E); bedding and cleavage in the Endicott Group (F-M); major fracture surfaces (N-P).

(B) Romanzof Chert

Equal
Area

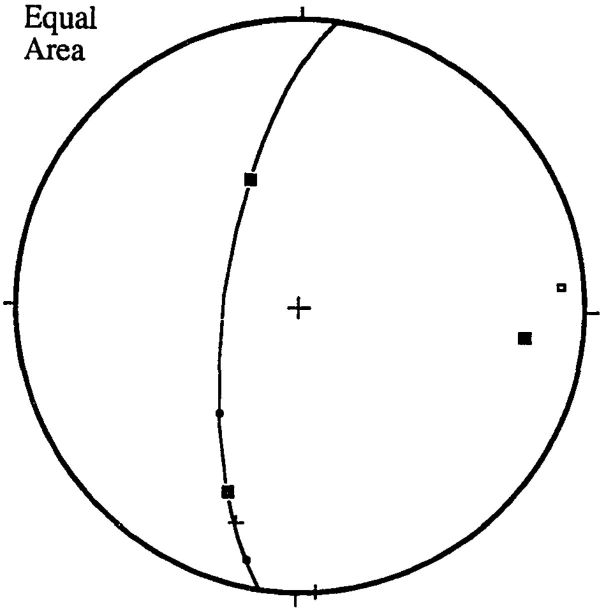


Location II A
D2 Fold

So = 14
FH = 7
AS = 6

BFGC = 187, 78 W
FA = 97, 12

Equal
Area



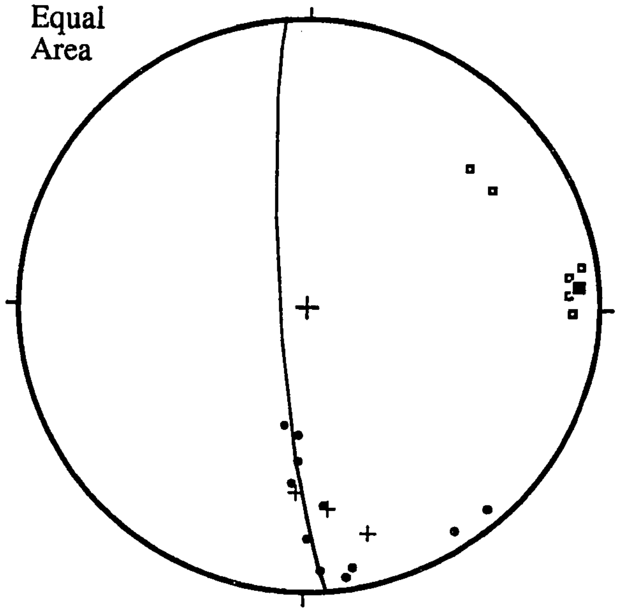
Location II B
D2 Fold

So = 2
FH = 2
AS = 1

BFGC = 187, 69 W
FA = 97, 21

(C) Romanzof Chert
Location III

Equal
Area

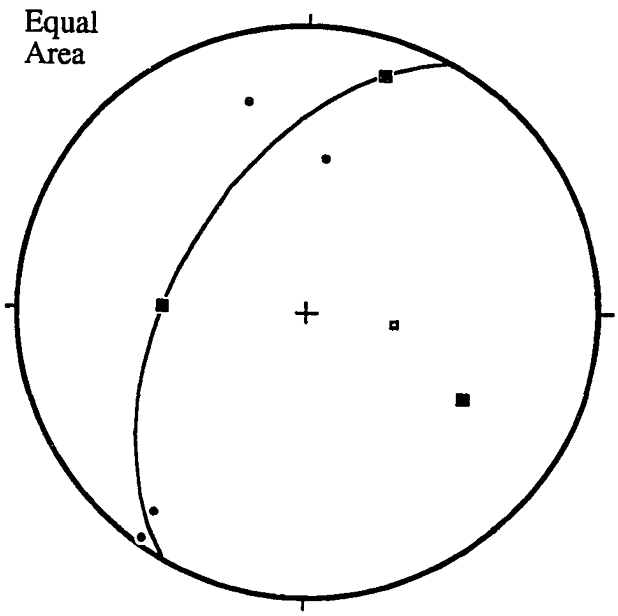


D2 Fold
N = 22

So = 11
FH = 6
AS = 3

BFGC = 175, 83 W
FA = 85, 7

Equal
Area

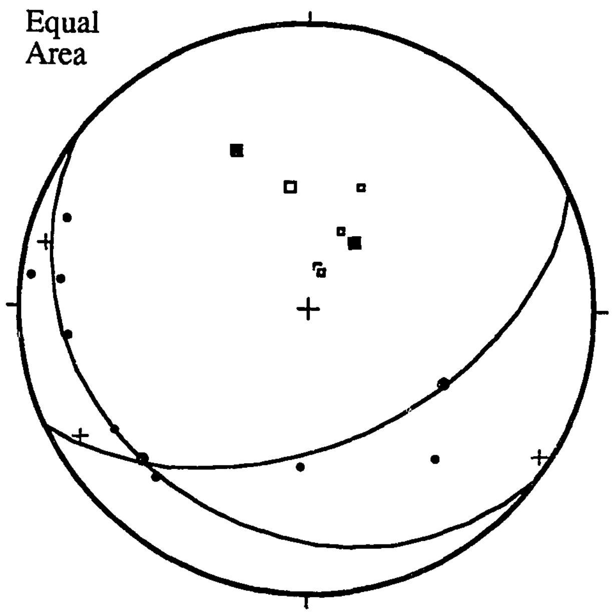


D1 Fold

So = 4
FH = 1

BFGC = 210, 52 W
FA = 120, 38

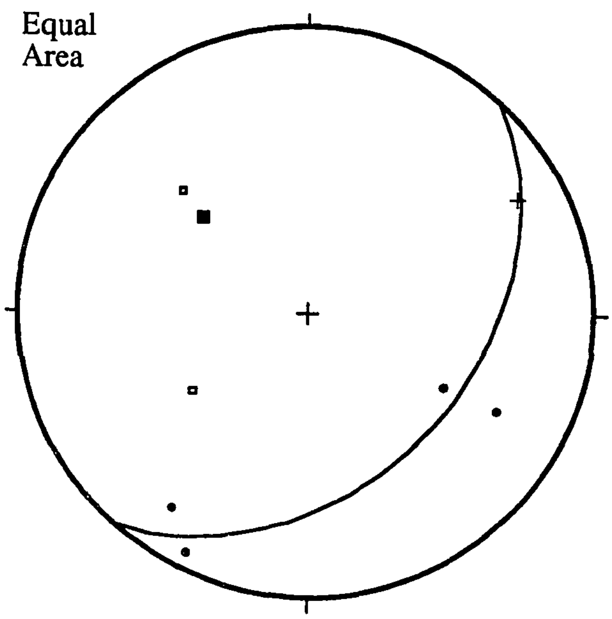
(D) Romanzof Chert
Location IV



D2 Fold

Synform
So = 2
FH = 1
BFGC = 66, 50 S
FA = 336, 40

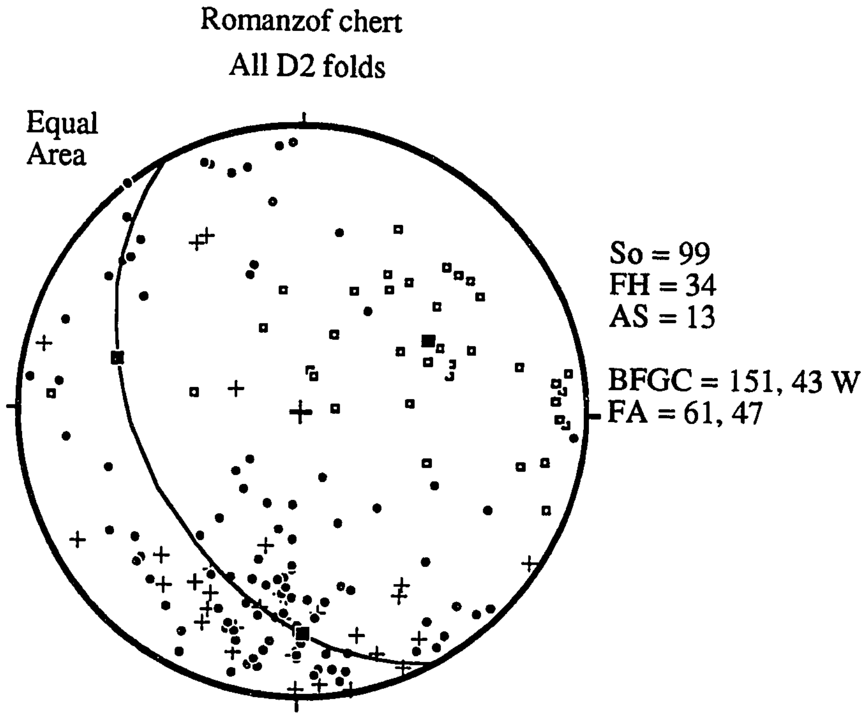
So = 8
FH = 4
SA = 3
Small Folds
BFGC = 126, 23 S
FA = 36, 67



D1 Fold
N = 7

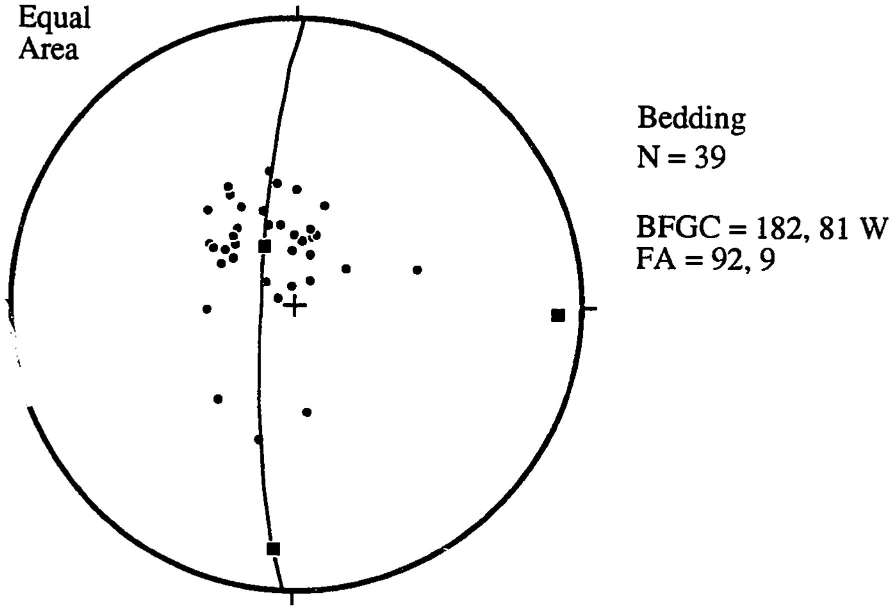
So = 4
FH = 2
SA = 1
BFGC = 42, 40 E
FA = 312, 50

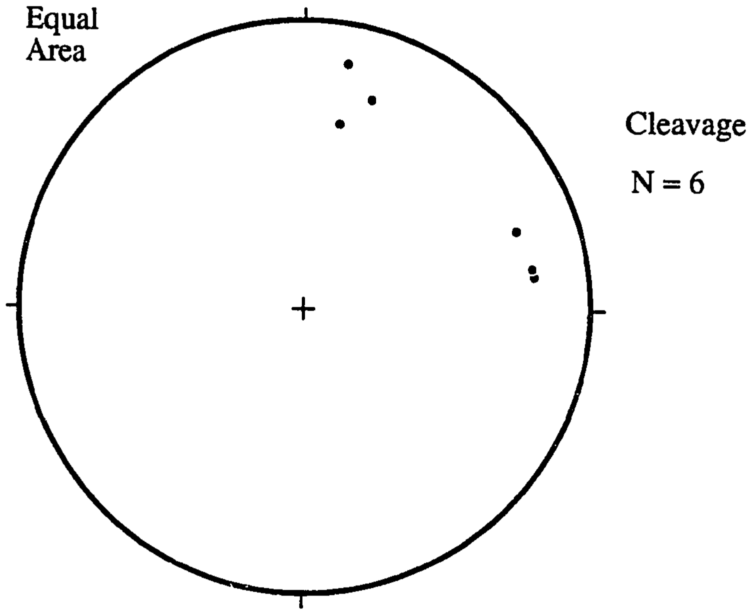
(E)


Romanzof chert
All D2 folds
Equal
Area
So = 99
FH = 34
AS = 13
BFGC = 151, 43 W
FA = 61, 47

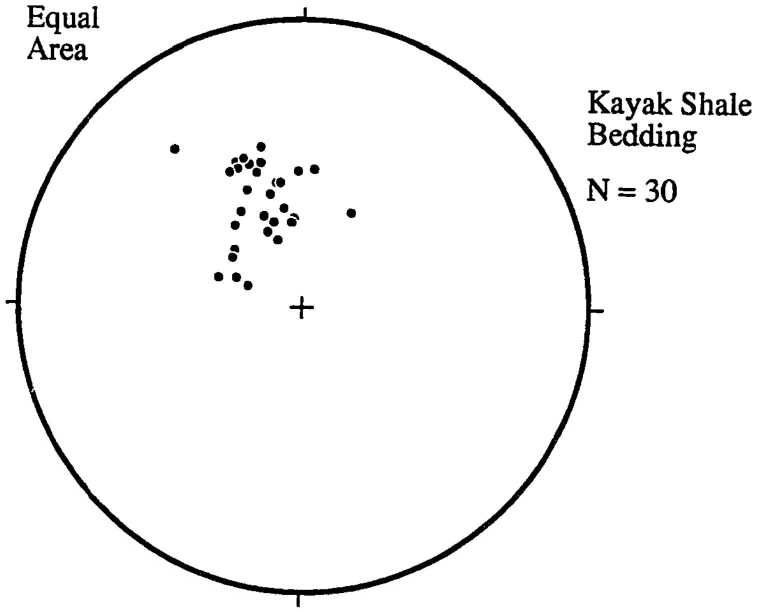
(F)

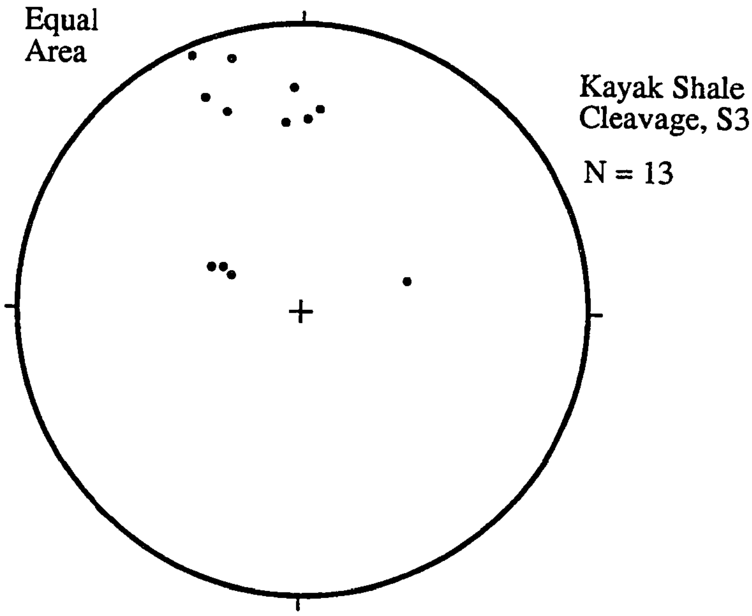
West Fork Valley Sheet
Kekiktuk Conglomerate



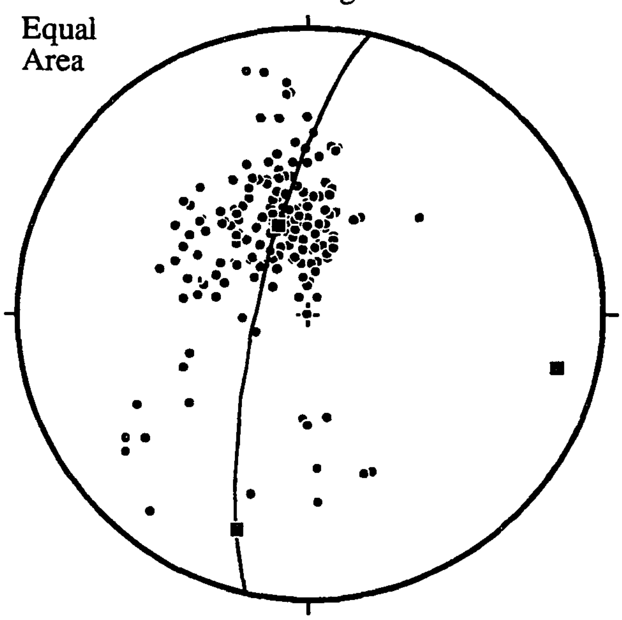


(G) West Fork Valley Thrust Sheet



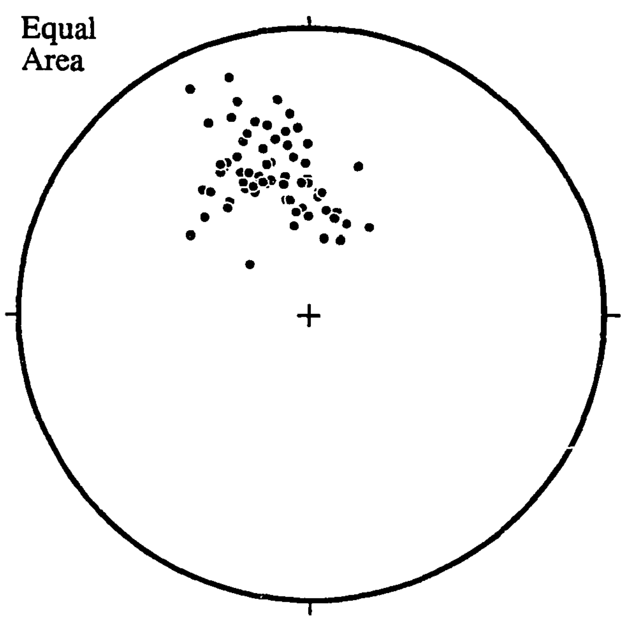


(H) Aichilik Pass Thrust Sheet
Ulungarat Formation, Mangaqtaaq Formation
Kekiktuk Conglomerate



Bedding
N = 178

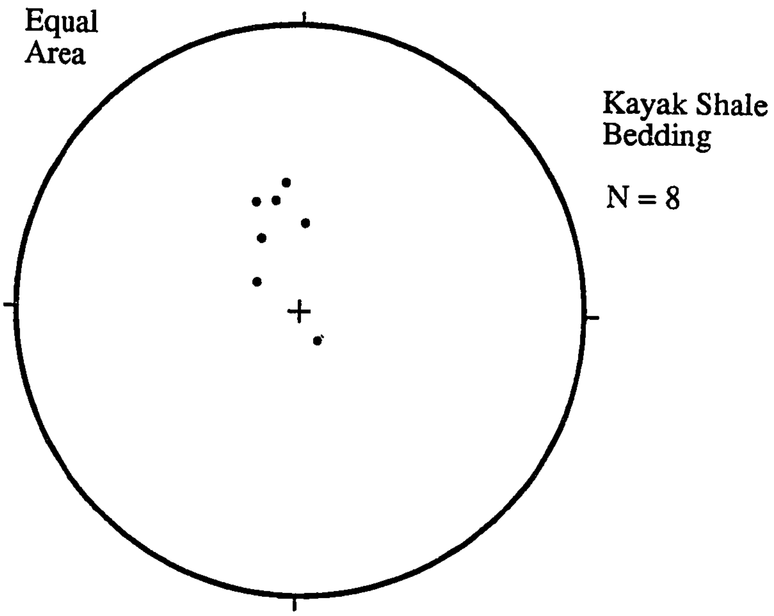
BFGC = 192, 76 W
FA = 102, 14

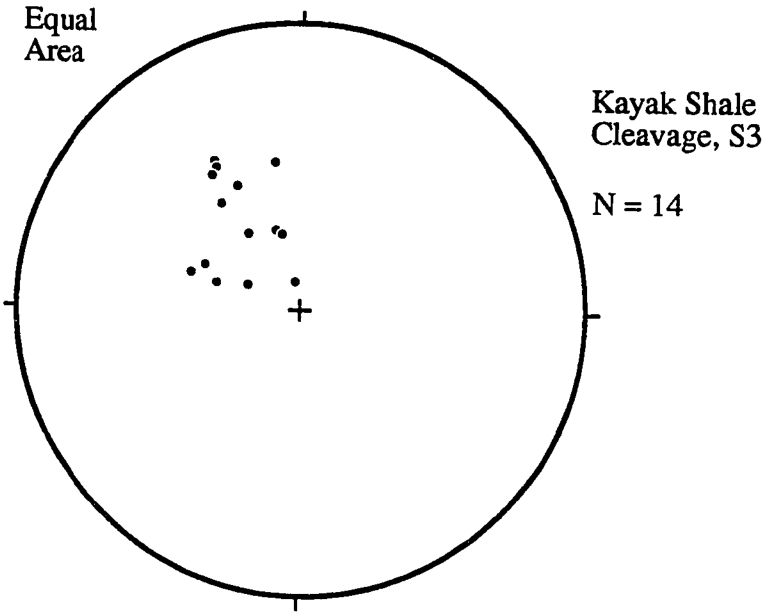


Cleavage
N = 69

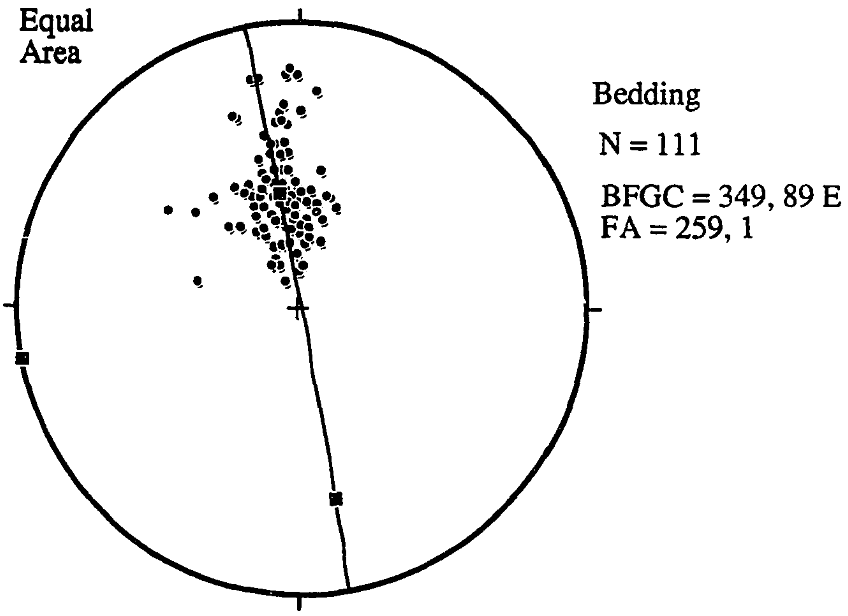
(I)

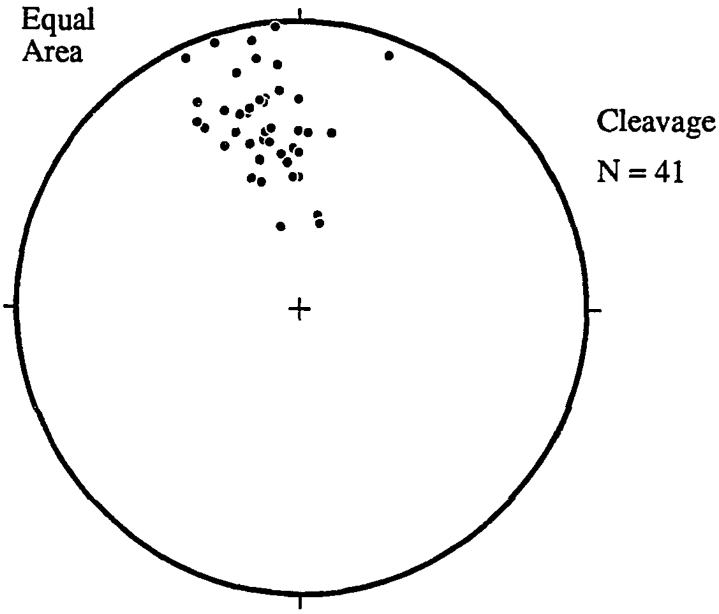
Aichilik Pass Thrust Sheet



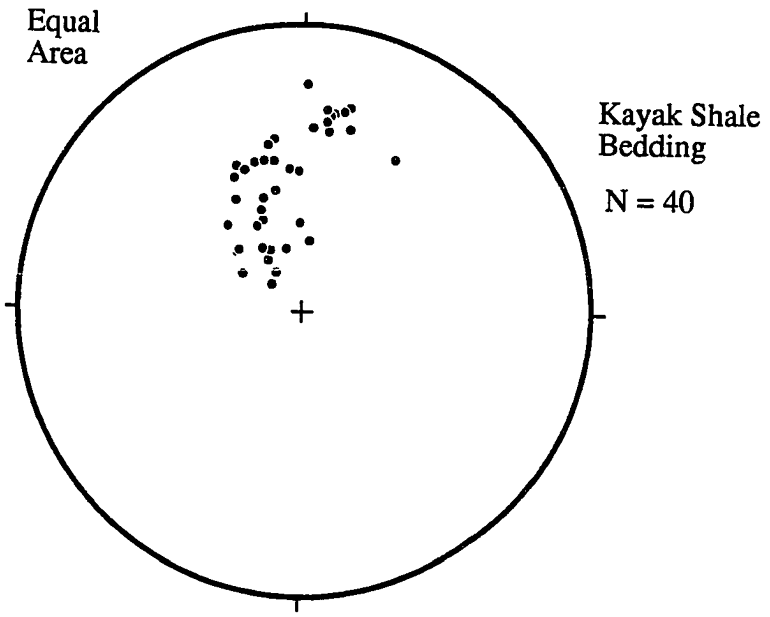


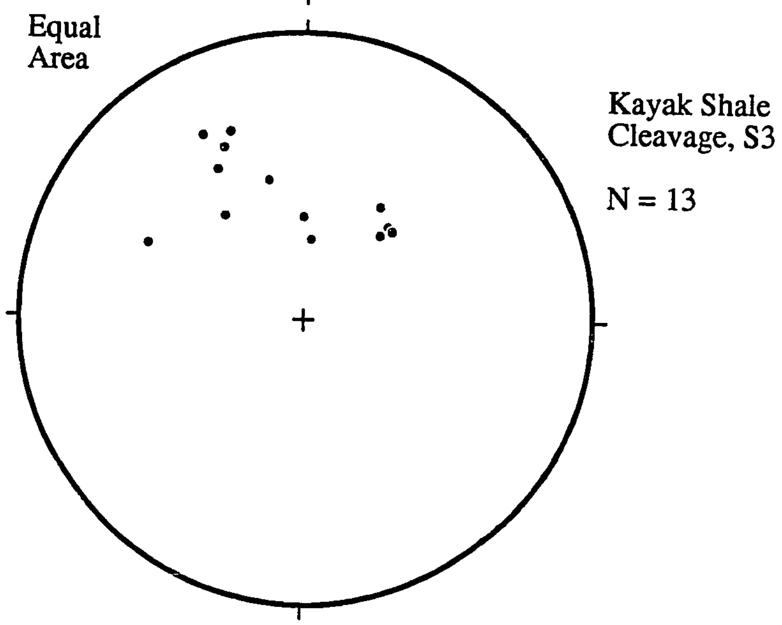
(J) Kongakut River Thrust Sheet
Ulungarat Formation, Mangaqtaaq Formation
Kekiktuk Conglomerate



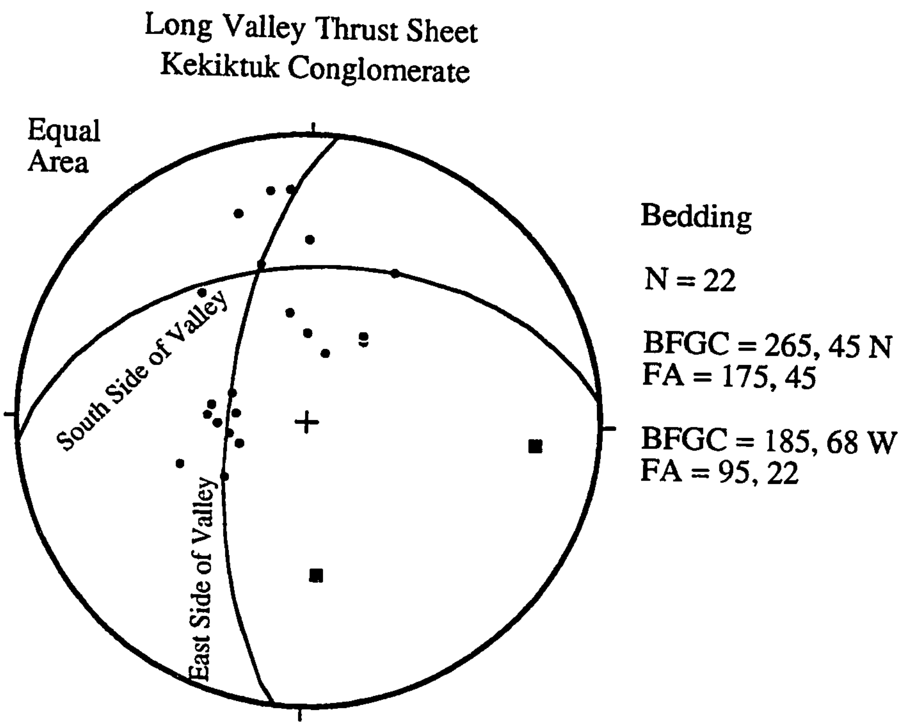


(K) Kongakut River Thrust Sheet

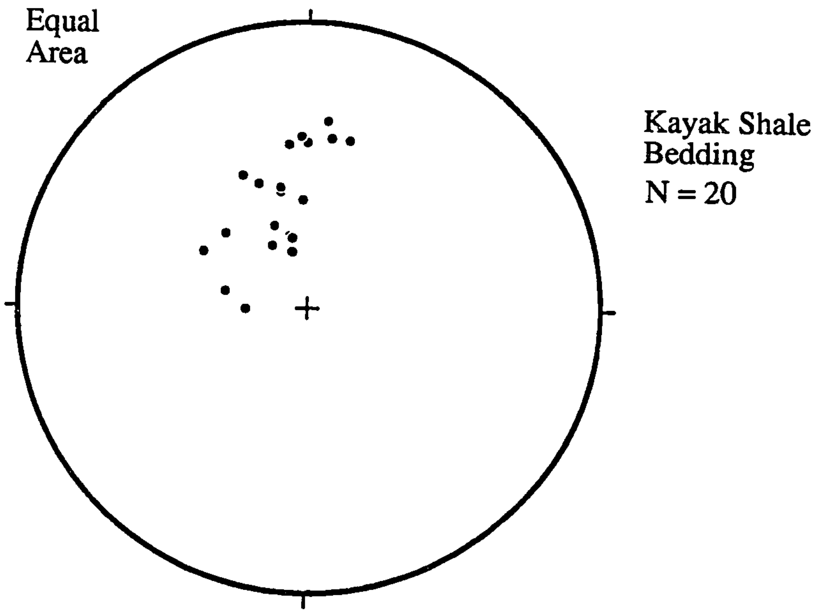


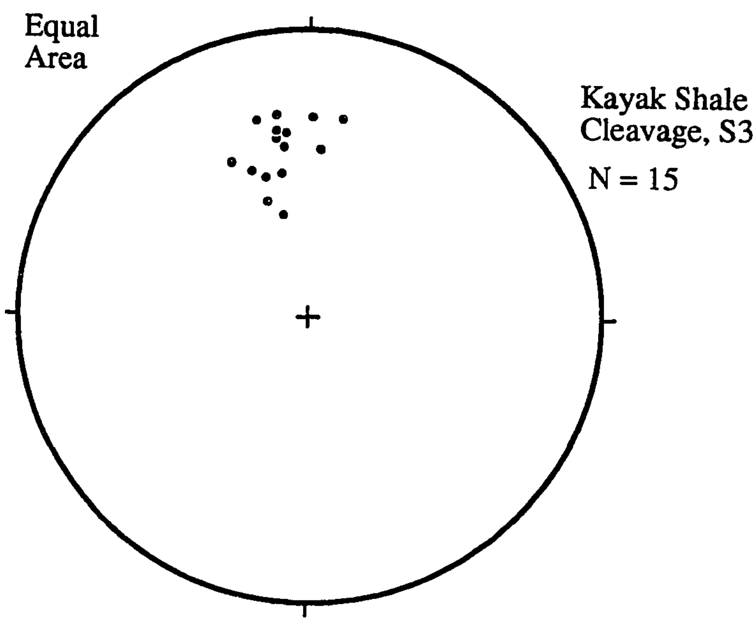


(L)


Long Valley Thrust Sheet
Kekiktuk Conglomerate
Equal
Area
South Side of Valley
East Side of Valley
Bedding
N = 22
BFGC = 265, 45 N
FA = 175, 45
BFGC = 185, 68 W
FA = 95, 22

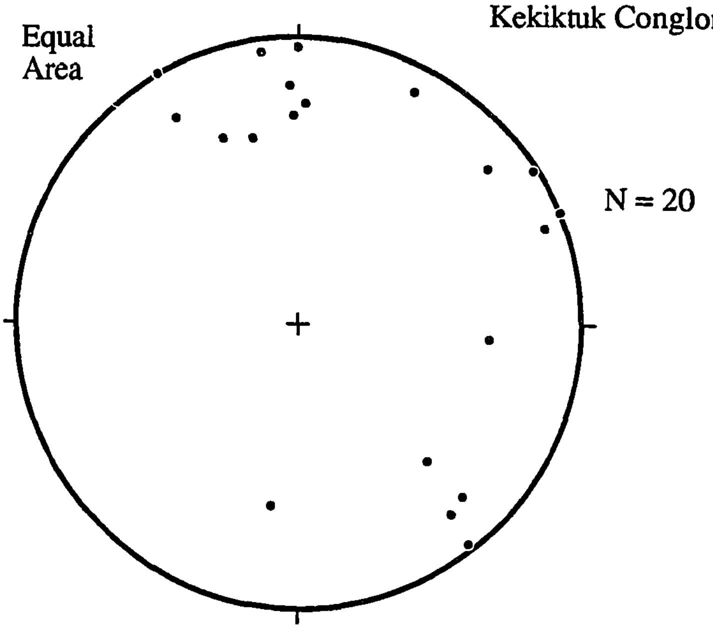
(M) Long Valley Thrust Sheet



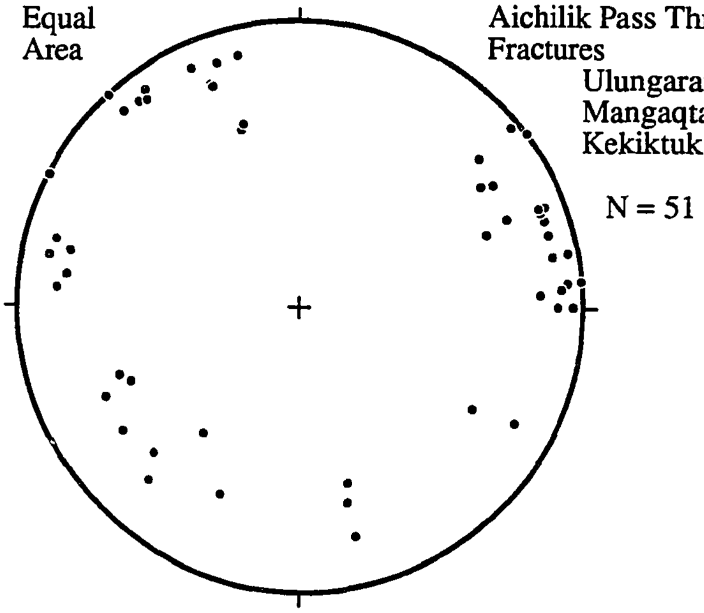


(N)

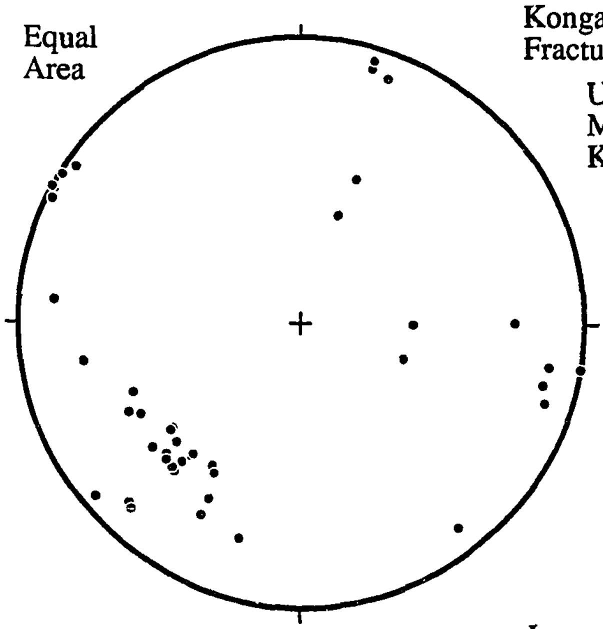
West Fork Valley Thrust Sheet
Fractures
Kekiktuk Conglomerate

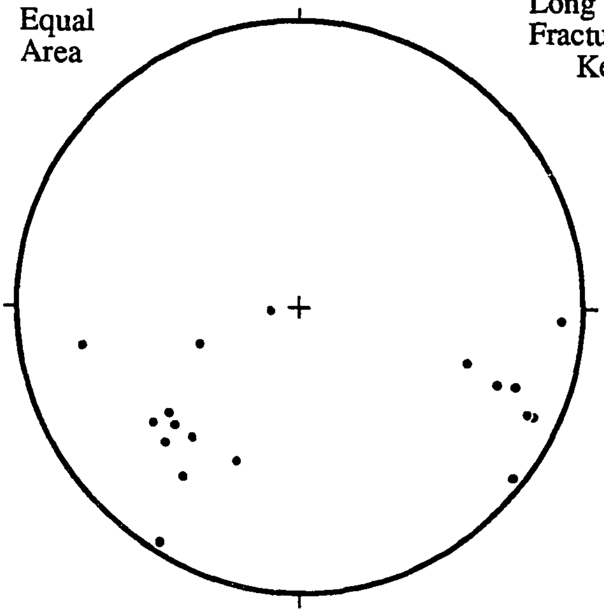


Aichilik Pass Thrust Sheet
Fractures
Ulungarat Formation
Mangaqtaaq Formation
Kekiktuk Conglomerate

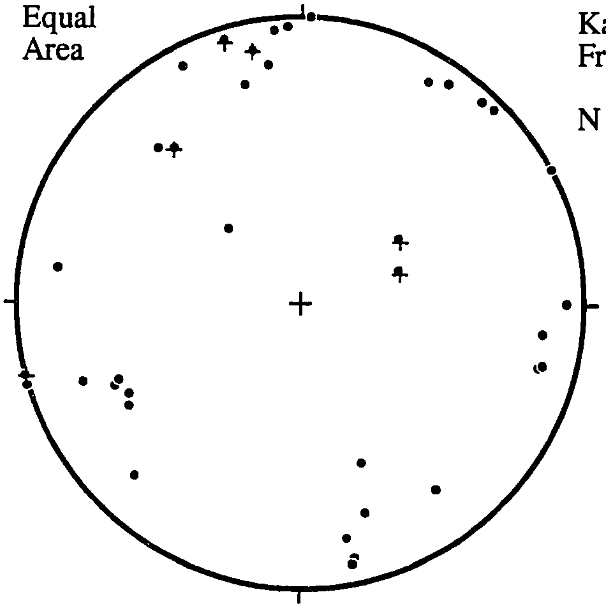


(O)


Equal
Area
Kongakut River Thrust Sheet
Fractures
Ulungarat Formation
Mangaqtaaq Formation
Kekiktuk Conglomerate
N = 42


Equal
Area
Long Valley Thrust Sheet
Fractures
Kekiktuk Conglomerate
N = 18

(P)



PLEASE NOTE:

Oversize maps and charts are filmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

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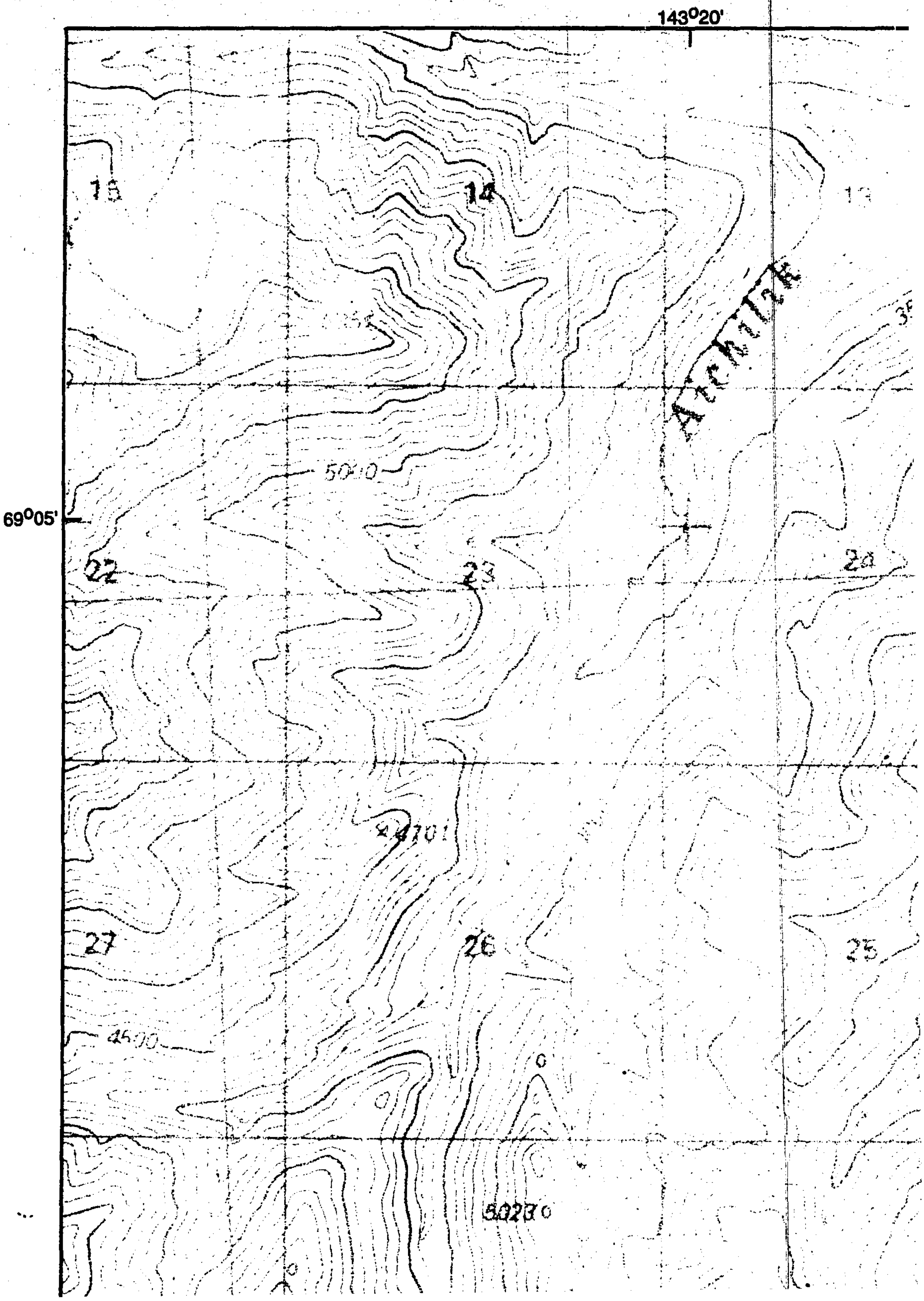

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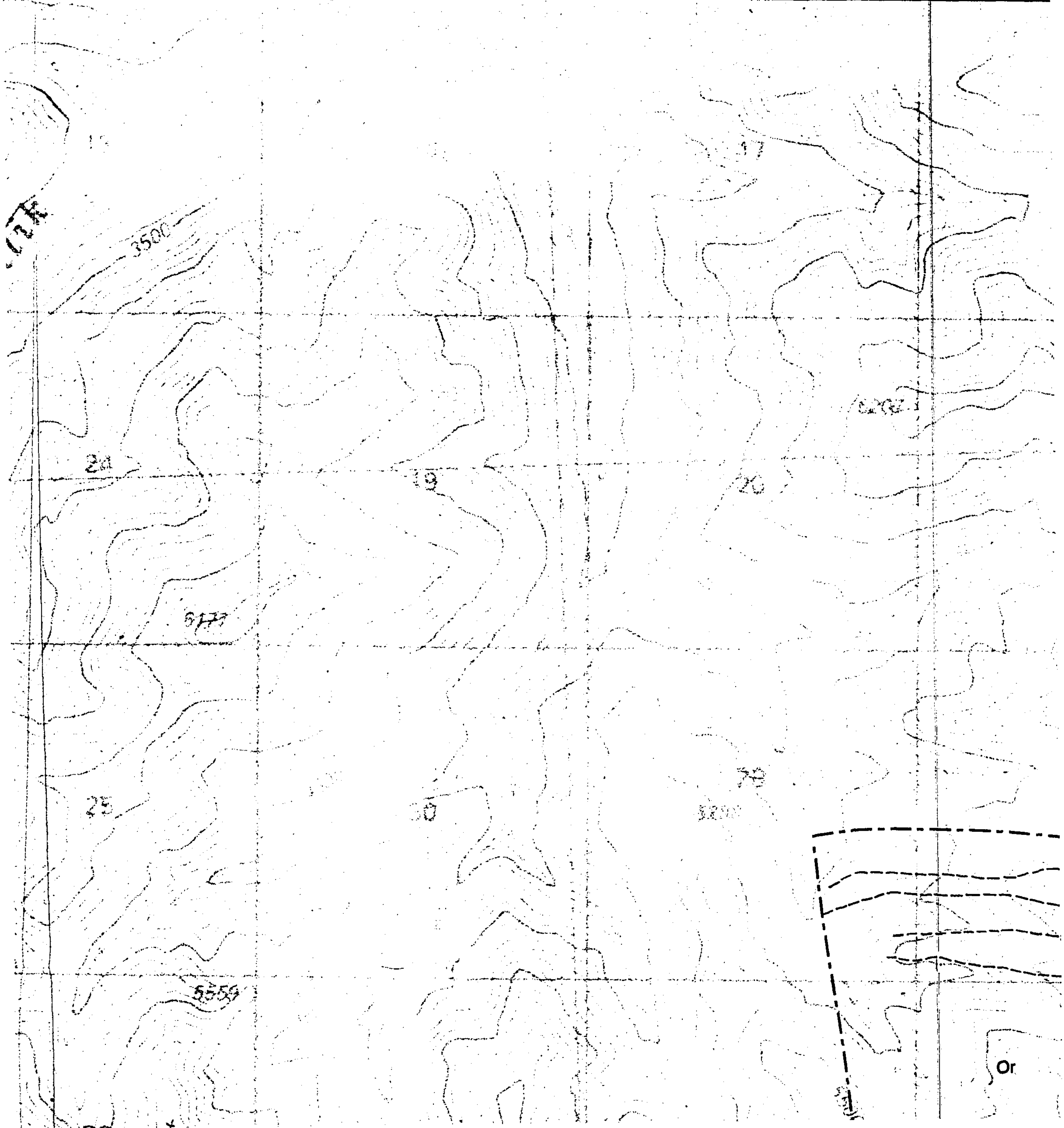

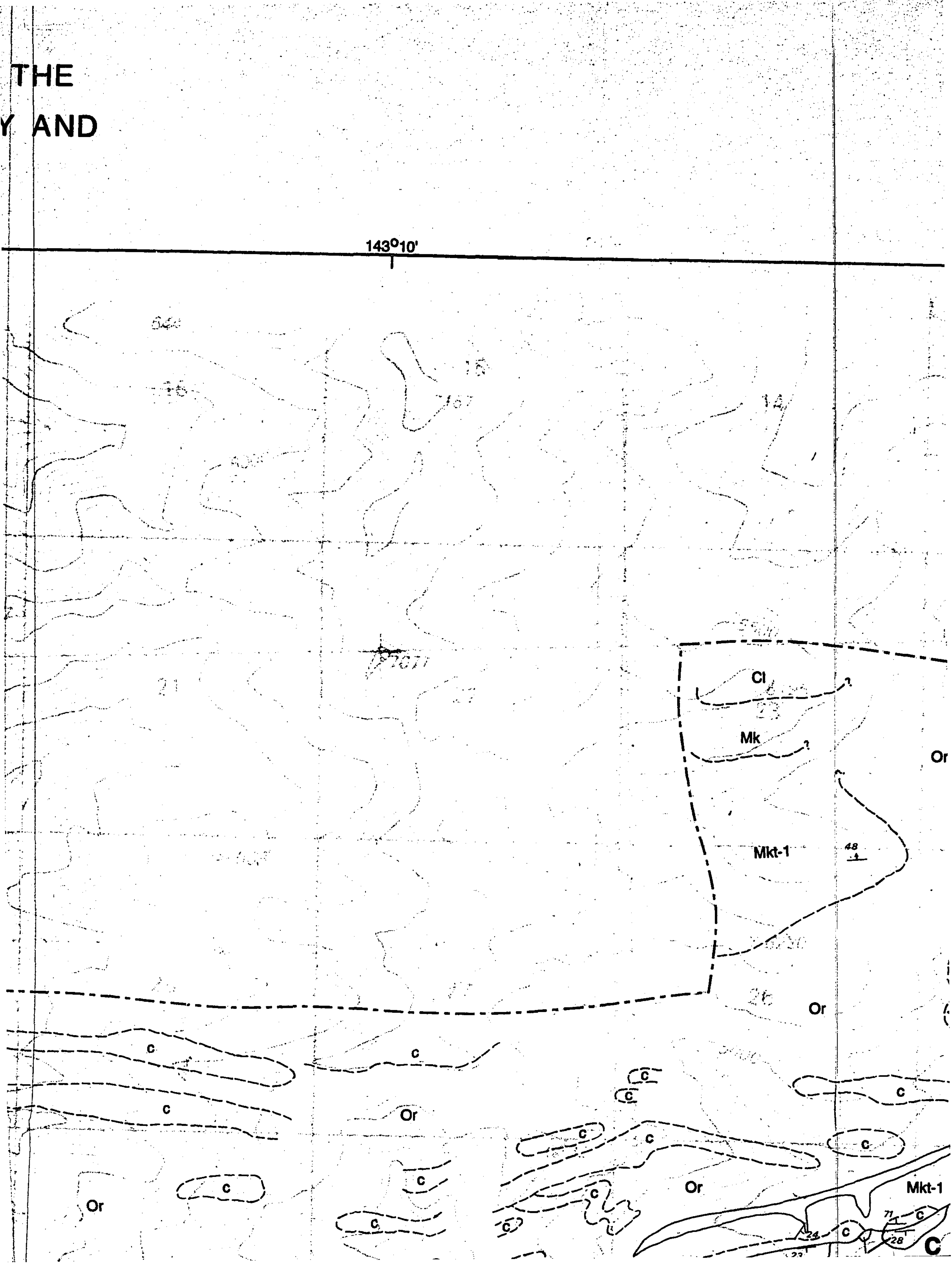
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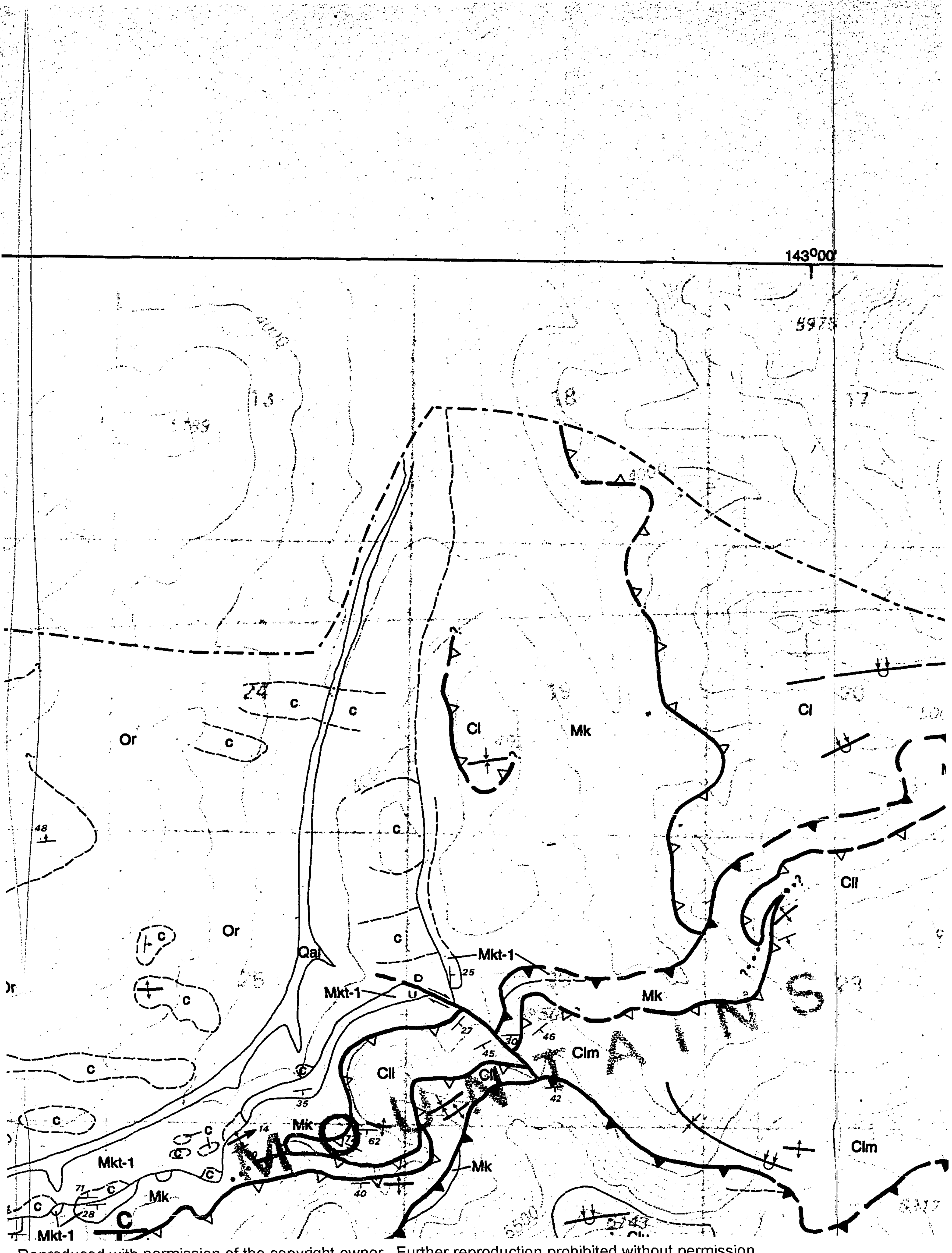
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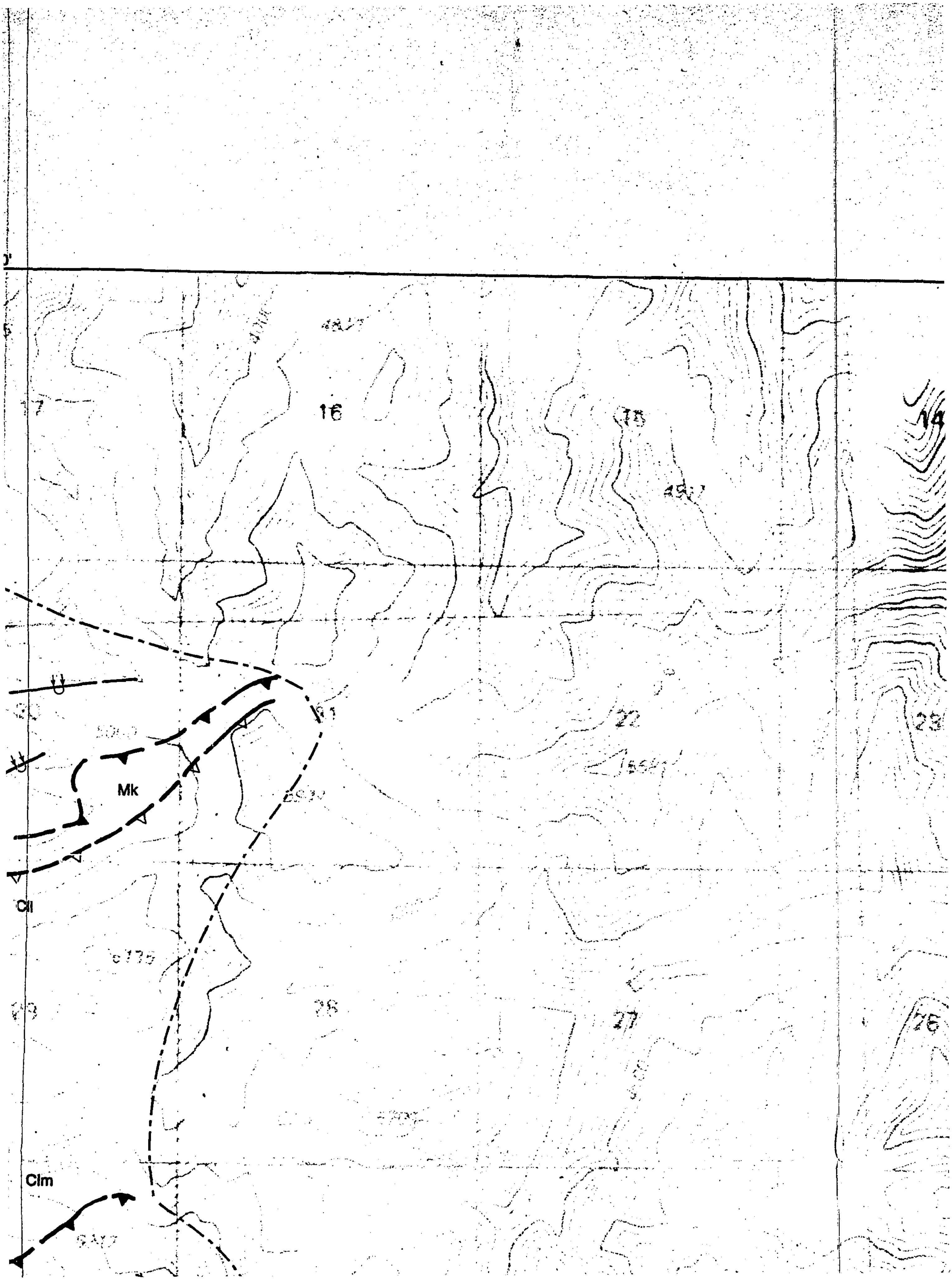
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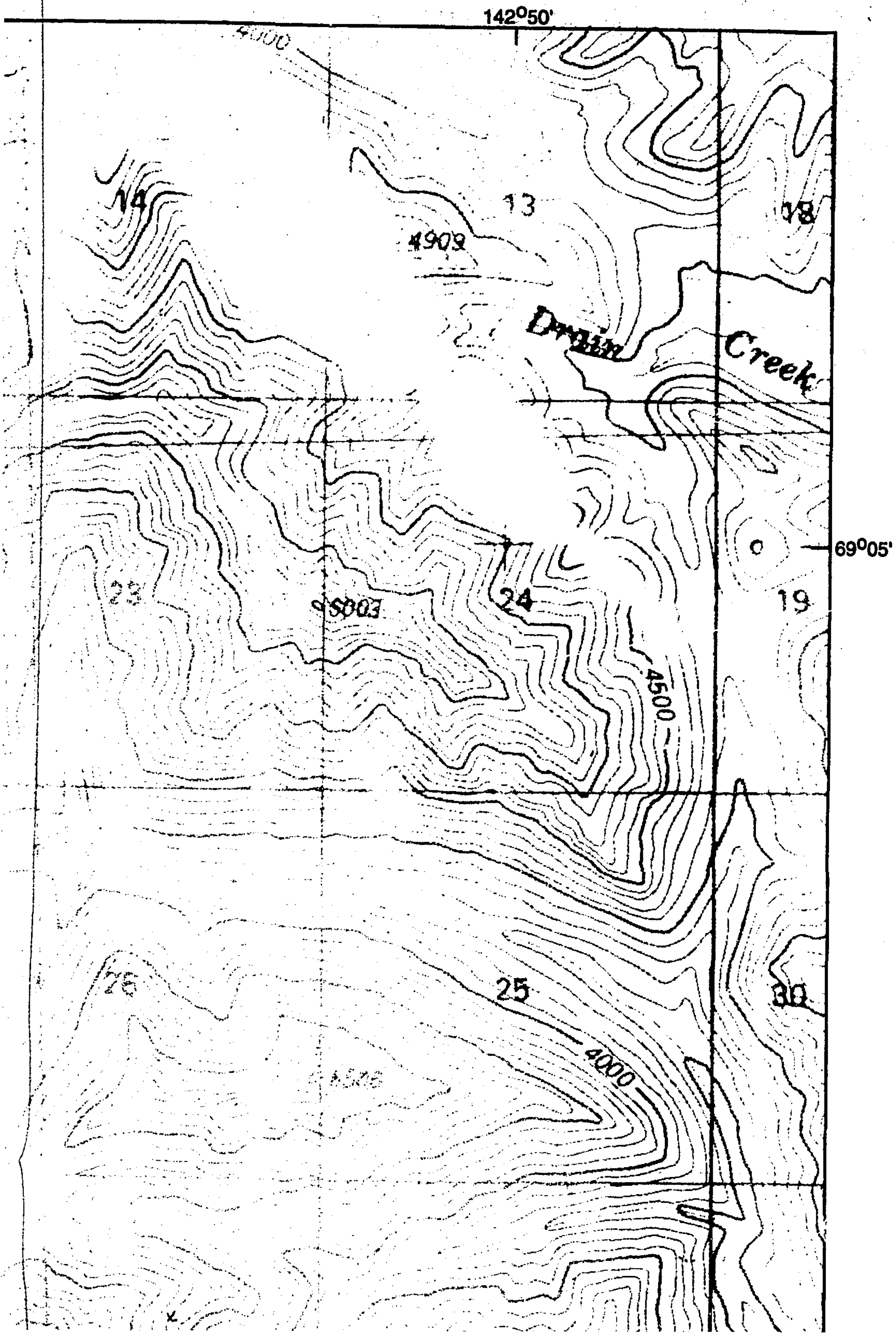

Qg GLACIERS

Qal ALLUVIUM -

Qu SURFICIAL D

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Formation - S
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SANDSTONE
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black mudston
part of Kayak

PLATE 1:
GEOLOGIC MAP AN
HEADWATERS OF T
AICHILIK RIVERS

PUBLIC DATA FILE 93-77

Anderson, Sheet 1 of 1

DESCRIPTION OF MAP UNITS

QUATERNARY

g GLACIERS

al ALLUVIUM - Stream gravels, terrace gravels

lu SURFICIAL DEPOSITS, UNDIVIDED

SADLEROCHIT GROUP

Ps SADLEROCHIT GROUP, UNDIVIDED - Ivishak Formation - Sandstone, light-gray, weathers reddish-brown, medium-grained, thinly and regularly bedded with ripple cross-lamination. Underlain by dark gray silty shale with minor thin limy beds; may be Kavik Shale. Early Triassic age (Reiser and others, 1980). Echooka Formation - Sandstone, medium-grained, thin- to medium-bedded, fossiliferous. Permian age (Reiser and others, 1980). Thickness approximately 100 m.

Psi IVISHAK FORMATION - Locally differentiated.

LISBURNE GROUP

l LISBURNE GROUP, UNDIVIDED - Bioclastic limestone and micrite divided into three units. Forms short-wavelength (100's meters) folds above a detachment horizon in Kayak Shale. Forms cliffs. Thickness variable due to erosion and structural thickening, approximate thickness 800 to 1000 m. Late Mississippian to Early Pennsylvanian age (Reiser and others, 1980).

u UPPER PART - Fine-grained limestone, weathers light gray to yellowish cream. Forms high cliffs.

n MIDDLE PART - Bioclastic limestone. Weathers gray to very dark gray. Forms ledges and slopes. Has acted as a detachment horizon where Cll is present. Commonly structurally thickened. Early Late Meramecian (locality 1) (A. Harris, U.S. Geological Survey, pers. comm., 1991).

ll LOWER PART- Bioclastic limestone, in places pervasively replaced by black chert as nodules and layers. Weathers medium-gray to black. Forms steep cliffs. Locally depositionally absent. Less than 30 m thick.

KAYAK SHALE

k KAYAK SHALE, UNDIVIDED - Shale, steel gray to black; very finely fissile; in places phyllitic; in places siltstone with abundant plant fossils; carbonaceous; forms low passes and valleys beneath the Lisburne Group limestones; forms steep loose slopes where structurally overlain by Kekiktuk conglomerate and Ulungarat Formation; structurally thickened; 300 to 400 m thick in the southern part of the map area; approximately 100 m thick in the northern part of the map area; everywhere an important detachment horizon, even where in normal stratigraphic order. Location of detachment within Kayak Shale is uncertain except where specifically shown. Mississippian (Late Tournaisian to Visean) age based on conodonts (locality 2) and trilobites (locality 3). Contains locally differentiated sandstone and limestone units.

:l UPPER LIMESTONE - Bioclastic limestone, thin-bedded, upward-thickening intervals in fissile, calcareous black mudstone and siltstone. Weathers yellowish-brown to black. Crinoid and brachiopod debris common; ironstone concretions with pyrite centers. Commonly forms disharmonic folds below Lisburne Group. Present throughout the map area, but only locally differentiated where greater than 20 m thick. Generally mapped as part of Kayak Shale undivided. 2 to 40 m thick.

SANDSTONE - Sandstone, gray, medium to coarse-grained quartzitic; amalgamated beds; low-angle trough cross-beds; rare preservation of shale interbeds, some coal; base is abrupt and irregular on underlying black mudstone (Mk). Overlain by black mudstone (Mk). In southeastern part of map area present in upper part of Kayak (Mksu). In south-central part of map area present in lower part of ...

PUBLIC DATA FILE 93-77

Anderson, Sheet 1 of 1

PLATE 1:
GEOLOGIC MAP AND CROSS-SECTIONS
HEADWATERS OF THE KONGAKUT AND
AICHILIK RIVERS

DESCRIPTION OF MAP UNITS

QUATERNARY

ivels, terrace gravels

UNDIVIDED

SADLEROCHIT GROUP

>, UNDIVIDED - Ivishak Formation - Sandstone, light-gray, weathers reddish-brown, and regularly bedded with ripple cross-lamination. Underlain by dark gray silty shale ds; may be Kavik Shale. Early Triassic age (Reiser and others, 1980). Echooka medium-grained, thin- to medium-bedded, fossiliferous. Permian age (Reiser and s approximately 100 m.

· Locally differentiated.

LISBURNE GROUP

NDIVIDED - Bioclastic limestone and micrite divided into three units. Forms short- ers) folds above a detachment horizon in Kayak Shale. Forms cliffs. Thickness and structural thickening, approximate thickness 800 to 1000 m. Late Mississippian age (Reiser and others, 1980).

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stic limestone. Weathers gray to very dark gray. Forms ledges and slopes. Has it horizon where CII is present. Commonly structurally thickened. Early Late (A. Harris, U.S. Geological Survey, pers. comm., 1991).

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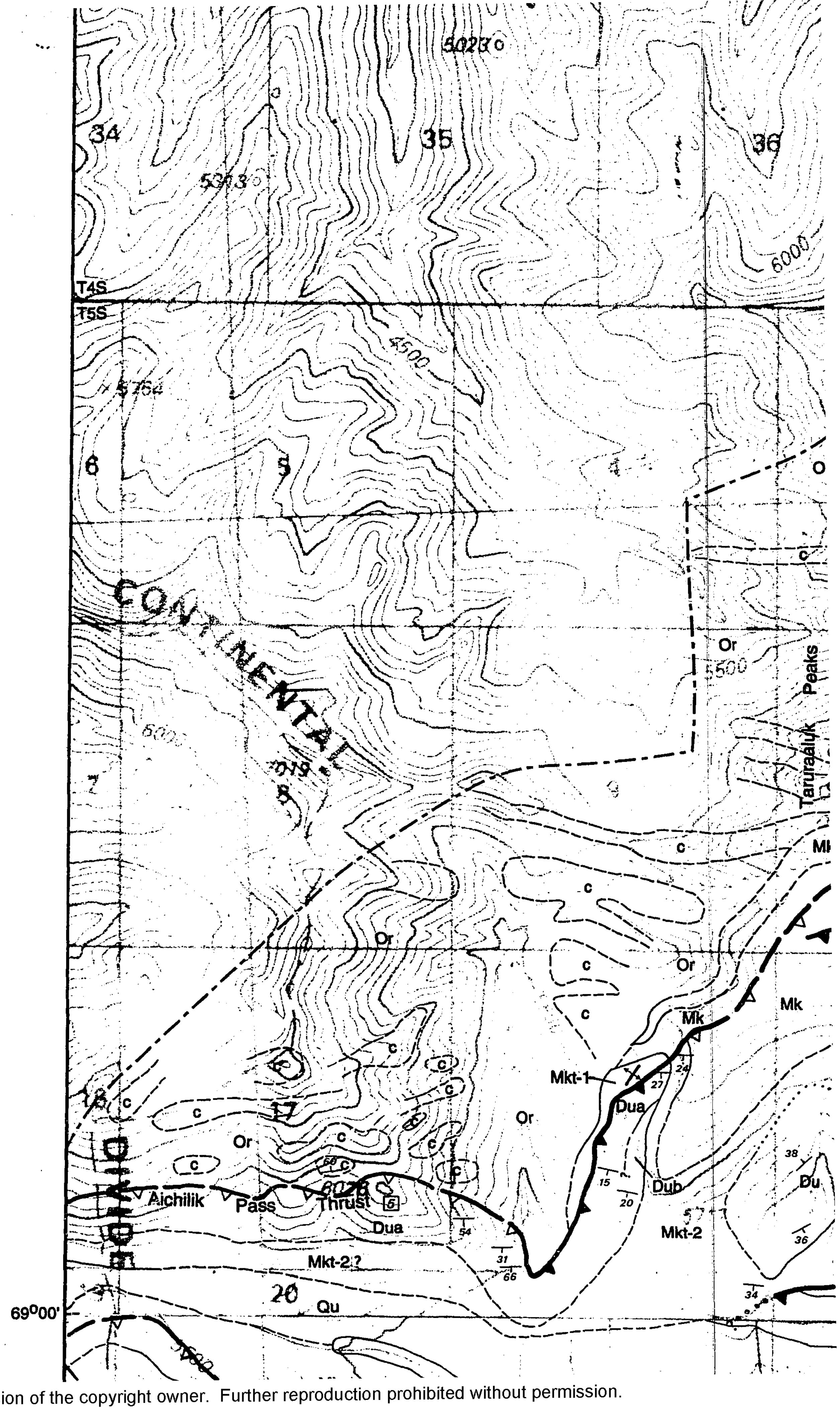
KAYAK SHALE

/IDED - Shale, steel gray to black; very finely fissile; in places phyllitic; in places plant fossils; carbonaceous; forms low passes and valleys beneath the Lisburne is steep loose slopes where structurally overlain by Kekiktuk conglomerate and tructurally thickened; 300 to 400 m thick in the southern part of the map area; iick in the northern part of the map area; everywhere an important detachment normal stratigraphic order. Location of detachment within Kayak Shale is uncertain lly shown. Mississippian (Late Tournaisian to Visean) age based on conodonts (locality 3). Contains locally differentiated sandstone and limestone units.

Bioclastic limestone, thin-bedded, upward-thickening intervals in fissile, calcareous stone. Weathers yellowish-brown to black. Crinoid and brachiopod debris common; with pyrite centers. Commonly forms disharmonic folds below Lisburne Group. map area, but only locally differentiated where greater than 20 m thick. Generally k Shale undivided. 2 to 40 m thick.

one, gray, medium to coarse-grained quartzitic; amalgamated beds; low-angle trough vation of shale interbeds, some coal; base is abrupt and irregular on underlying)verlain by black mudstone (Mk). In southeastern part of map area present in upper In south-central part of map area present in lower part of Kayak (Mksl) at same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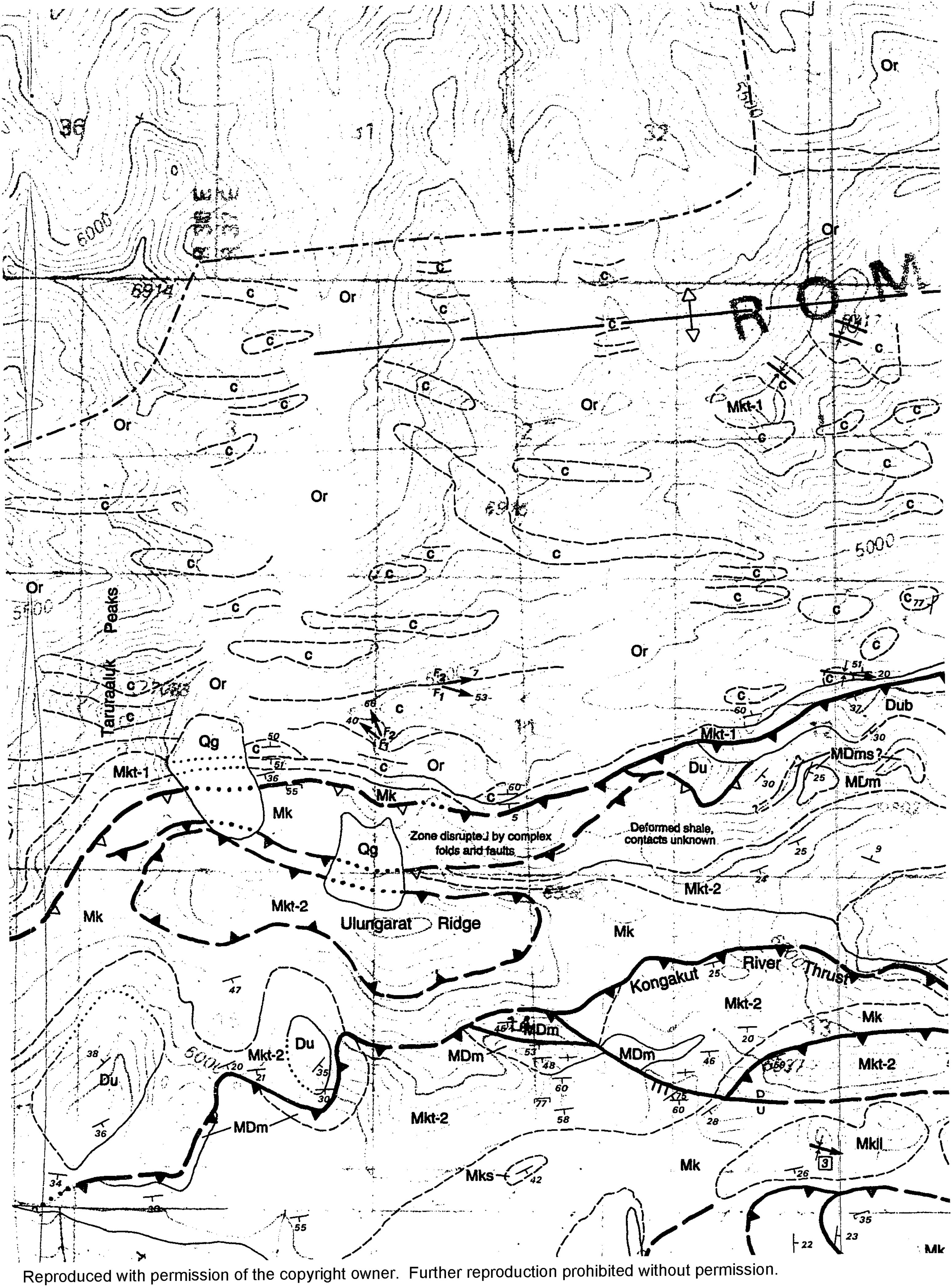
ROM
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Mkt-2
Ulungarat Ridge
Zone disrupted by complex folds and faults
Deformed shale, contacts unknown
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Kongakut River Thrust
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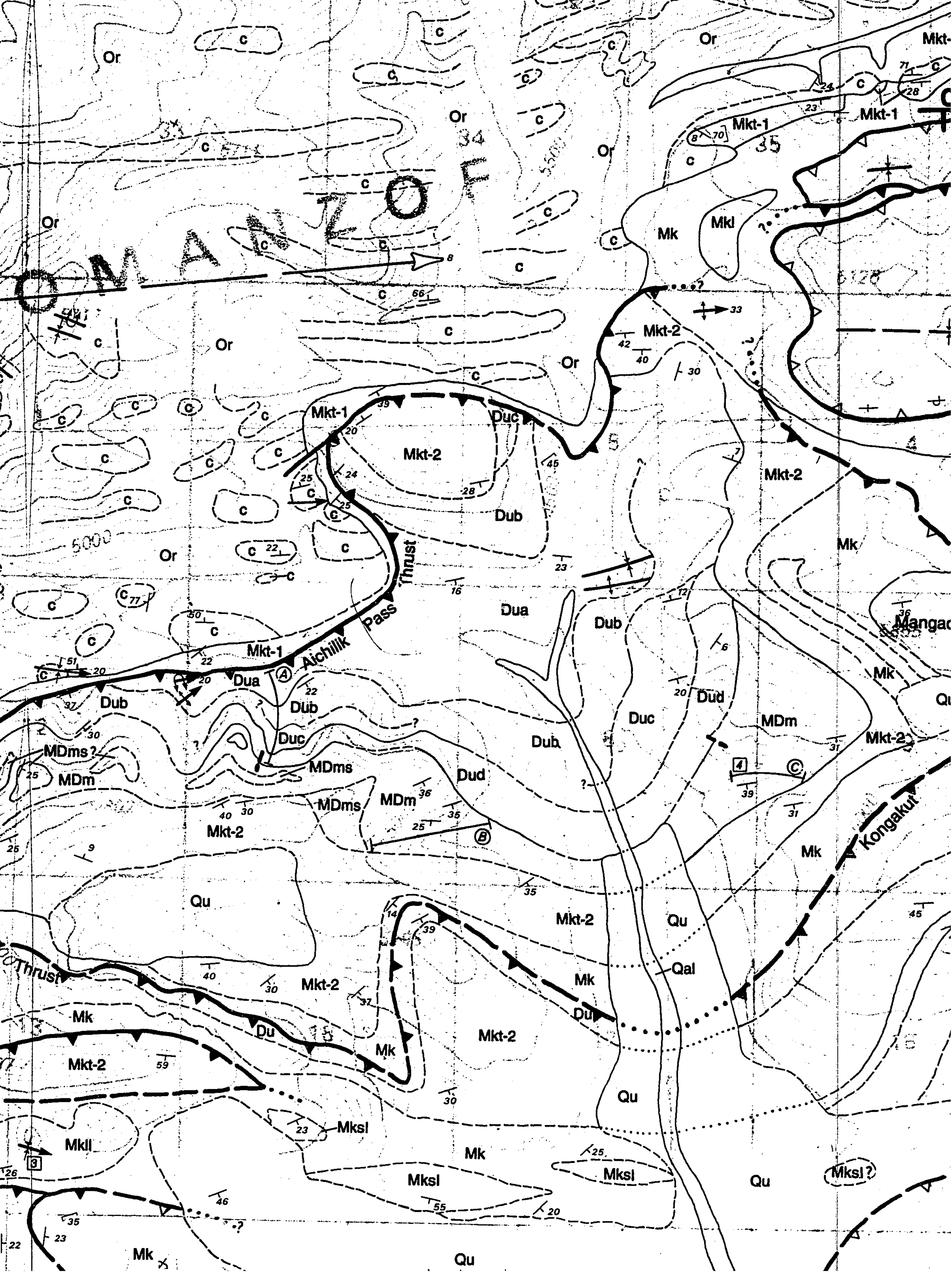
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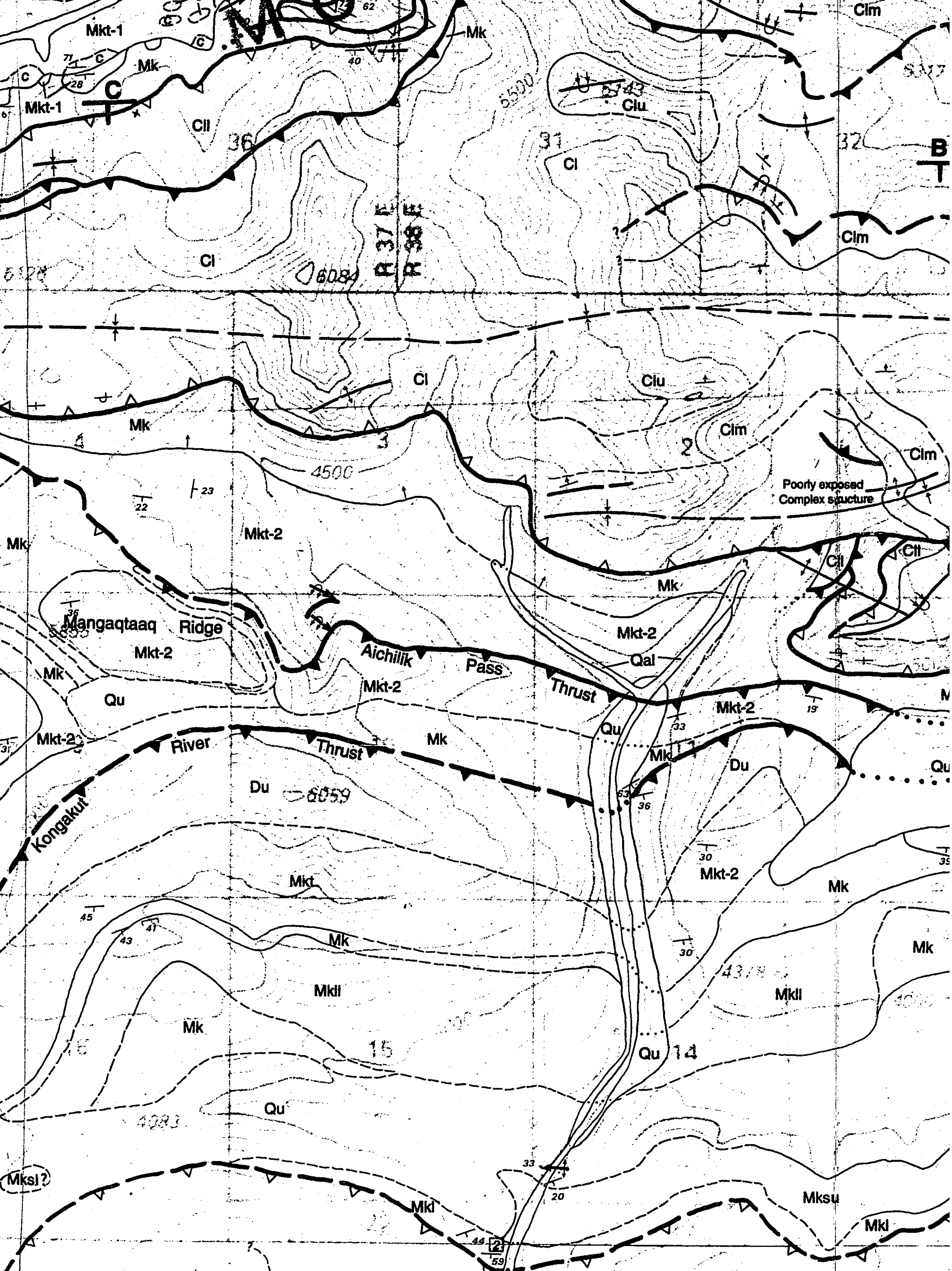
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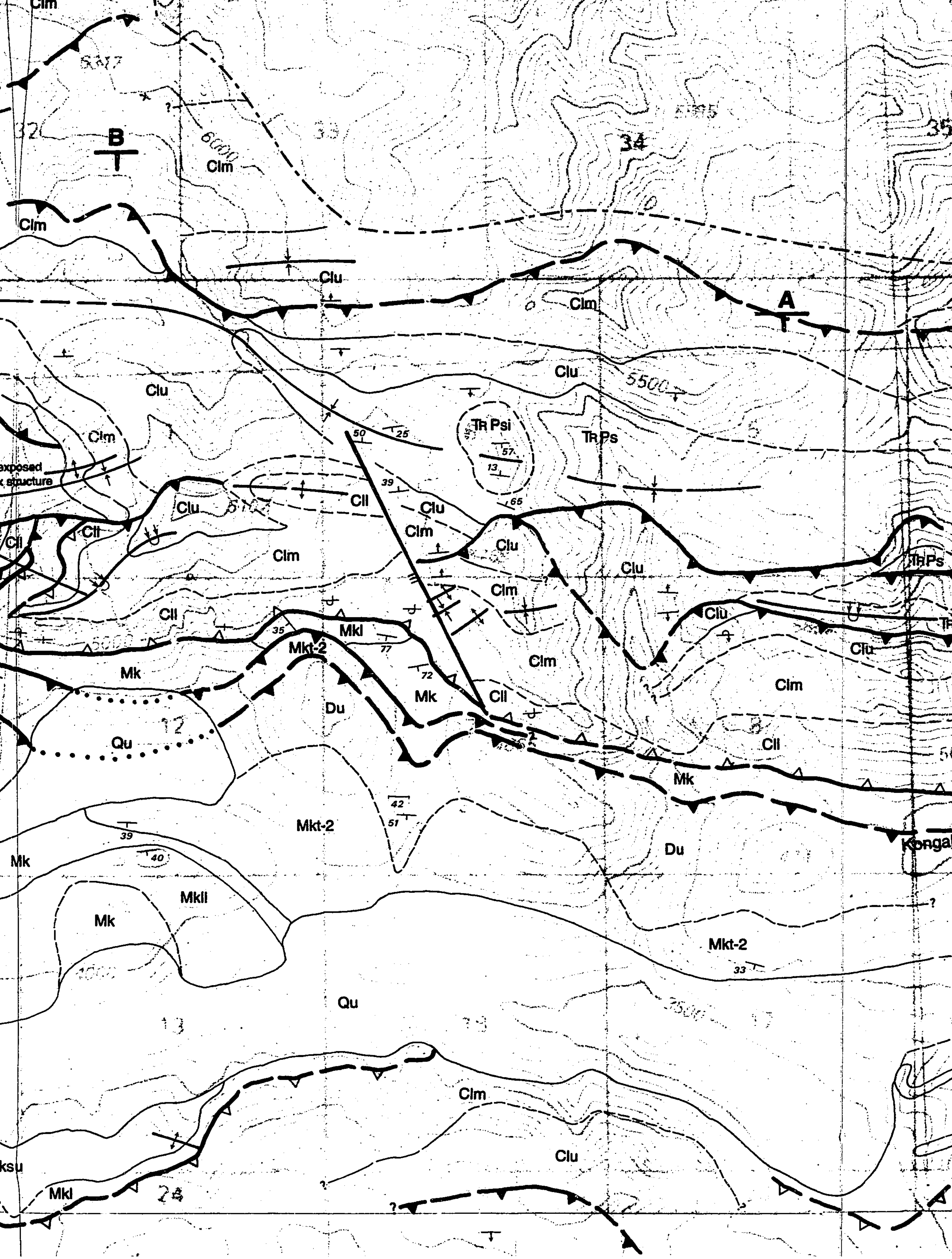

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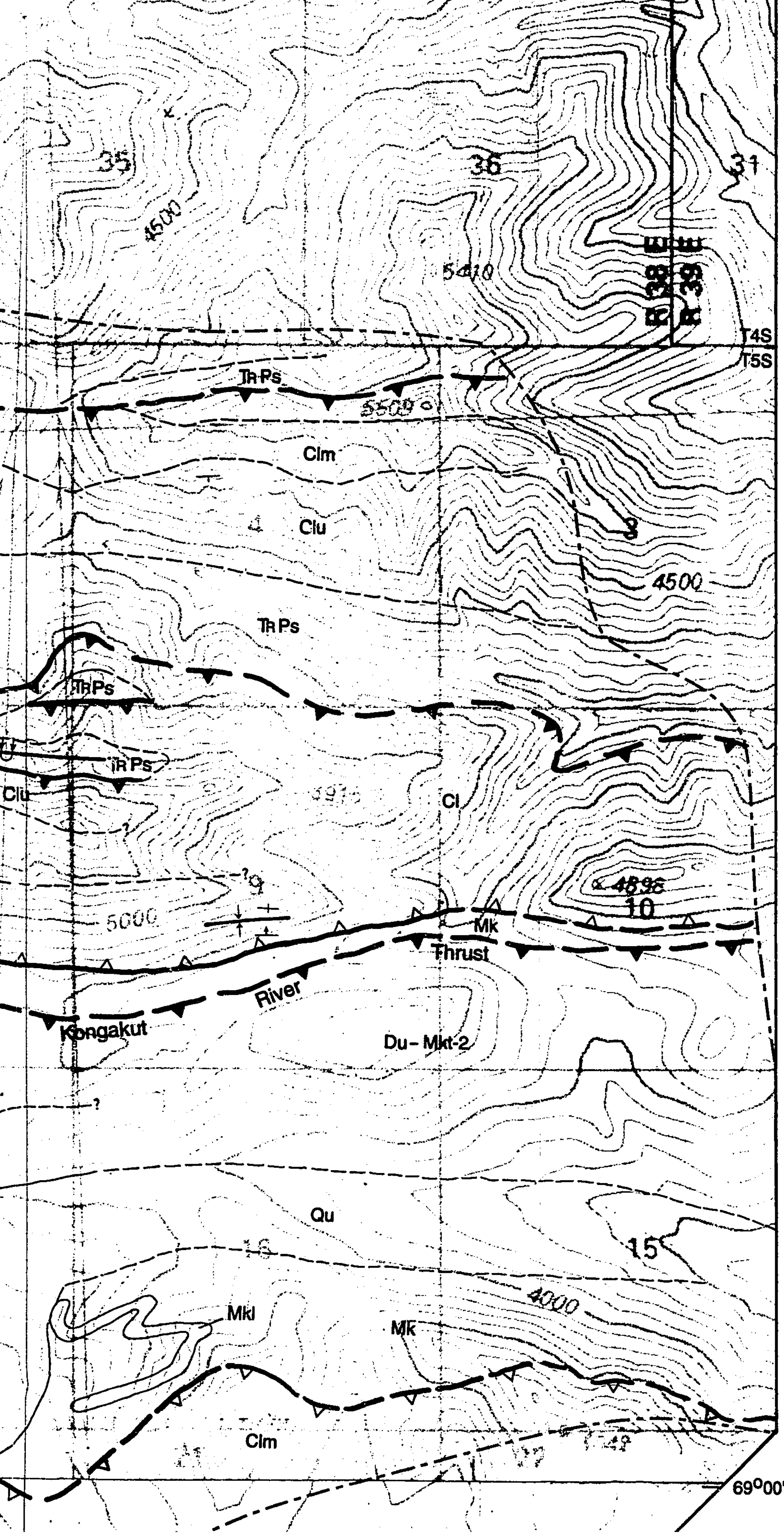


	Present throug mapped as pa
Mks Mksu Mksl	SANDSTONE cross-beds; ra black mudston part of Kayak stratigraphic p
Mkll	LOWER LIME nodules. Inter
Mkt	KEKIKTUK C separated by a Or) controlled southern part c
Mkt-1	KEKIKTUK C sandstone; we lateral change As mapped, in m thick.
Mkt-2	KEKIKTUK C siltstone; cong up to 17 cm in cubic voids fro cracks, plant f angle discorda the map area. thick.
MDm	LIMESTONE - black shale. unconformably constrained as Geological Sur
MDms	(SANDSTONE contains sands
Du	ULUNGARAT from marine m Overall weathe on an interpret Consists of fou Geological Sur of member A a section is local
Dud	(MEMBER D) sandstone bodi
Duc	(MEMBER C) stained yellow- major incised e thick and 50 to to, and overlie t
Dub	(MEMBER B) - channel-fills wit red. Individual mudcracks, roo
Dua	(MEMBER A) - weathers gray; bioturbated; thi slopes. Shallow

mapped as part of Kayak Shale undivided. 2 to 40 m thick.

s su sl SANDSTONE - Sandstone, gray, medium to coarse-grained quartzitic; amalgamated beds; low-angle trough cross-beds; rare preservation of shale interbeds, some coal; base is abrupt and irregular on underlying black mudstone (Mk). Overlain by black mudstone (Mk). In southeastern part of map area present in upper part of Kayak (Mksu). In south-central part of map area present in lower part of Kayak (Mksl) at same stratigraphic position as Mkll. Less than 15 meters thick.

kll LOWER LIMESTONE - Limestone, light gray, fossiliferous, contains large crinoid stems; some black chert nodules. Interbedded with black mudstone in lower part of Kayak Shale. Less than 50 meters thick.

KEKIKTUK CONGLOMERATE

kt KEKIKTUK CONGLOMERATE, UNDIVIDED - Divided into two sequences, Mkt-1 and Mkt-2, generally separated by a thrust fault. To the north, Mkt-1 is thin, with deposition on Ordovician chert and argillite (unit Or) controlled by local relief on the underlying unconformity surface. Mkt-2 is thicker and exposed in the southern part of the map area. Mississippian age.

-1 KEKIKTUK CONGLOMERATE, NORTHERN BELT - Quartz-chert breccia to pebble conglomerate and sandstone; weathers gray, often stained yellow-brown to rust-red, locally calcareous, fines upward; abrupt lateral changes in thickness. Basal breccia is difficult to distinguish from massive chert of Romanzof chert. As mapped, includes overlying siltstone and mudstone with abundant plant fossils. Generally less than 30 m thick.

2 KEKIKTUK CONGLOMERATE, SOUTHERN BELT - Quartz-chert pebble conglomerate, sandstone, and siltstone; conglomerate includes white, gray, lavender and less common black chert pebbles and cobbles up to 17 cm in diameter. Matrix is light gray to lavender-gray, grading light gray to white quartzite, contains cubic voids from leached pyrite. Some channel geometry, tabular cross-beds, ripple cross-lamination, mud cracks, plant fossils. Upward-fining intervals in an overall fining-upward succession. Deposited with low-angle discordance on Ulungarat Formation; grades abruptly upward into Kayak Shale in the southern part of the map area. Intertongues(?) with Kayak Shale in central part of the map area. Generally 40 to 130 m thick.

MANGAQTAAQ FORMATION (new name)

n LIMESTONE - Black algal limestone with prominent oncoids, interbedded with sandstone and organic rich black shale. Sandstone interbeds are cross-bedded and ripple cross-laminated. Interpreted to unconformably overlie Ulungarat Formation; unconformably overlain by Kekiktuk Conglomerate. Age poorly constrained as Late Devonian or Early Mississippian, based on plant fossils (locality 4) (S. Mamay, U.S. Geological Survey, pers. comm., 1989). Composite reference section localities B and C. 200 m thick.

ls (SANDSTONE UNIT) - Pebbly sandstone, subangular to angular chert pebbles; locally calcareous; locally contains sandstone dike which internally contains dish structures.

ULUNGARAT FORMATION (new name)

ULUNGARAT FORMATION, UNDIVIDED - Overall upward-thickening and -coarsening succession grading from marine mudstone and sandstone in lowest exposed strata upward to channelized conglomerate. Overall weathers red to brown. Base is a low-displacement thrust fault. Overlain by Mangaqtaaq Formation on an interpreted low-angle unconformity or by the Kekiktuk conglomerate on a low-angle unconformity. Consists of four informal members. The lowermost member is Middle Devonian (Eifelian, R. Blodgett, U.S. Geological Survey, pers. comm., 1992). The upper three members are bracketed between the Eifelian age of member A and the Mississippian age of the unconformably overlying Kekiktuk Conglomerate. Reference section is locality A.

(MEMBER D) - Rose-red and gray-green mottled mudstone and siltstone. Isolated, small, channelized sandstone bodies. 20 to 50 m thick.

(MEMBER C) - Chert granule to pebble conglomerate and sandstone; sandstones weather gray, often stained yellow-brown to rust-red. Thick successions of amalgamated conglomeratic channel-fill deposits fill major incised erosion surfaces. Forms steep cliff. Individual incised channel-fill successions are 20 to 30 m thick and 50 to 75 m wide. Brown-red mudstone with interbedded thin sandstone beds underlie, are lateral to, and overlie the cliff-forming conglomerates. Up to 110 m thick.

(MEMBER B) - Chert pebble conglomerate, sandstone, and siltstone in multiple, upward-fining sandstone channel-fills with intervening siltstone beds. Sandstones weather gray, often stained yellow-brown to rust-red. Individual channel fills are 1 to 3 m thick. Rose-red and green-gray mottled mudstone. Plant fossils, mudcracks, root casts. Up to 110 m thick.

(MEMBER A) - Upward-thickening and -coarsening succession of mudstone, siltstone, and sandstone; weathers gray; upper half of assemblage is dominated by thin, amalgamated sandstone beds. Commonly bioturbated; thin, fossiliferous calcareous beds occur near the base. Forms irregular weathering steep slopes. Shallow-marine invertebrate fauna of Middle Devonian (Eifelian) age (locality 5). Up to 160 m thick.

...shale undivided. 2 to 40 m thick.

tone, gray, medium to coarse-grained quartzitic; amalgamated beds; low-angle trough ervation of shale interbeds, some coal; base is abrupt and irregular on underlying Overlain by black mudstone (Mk). In southeastern part of map area present in upper In south-central part of map area present in lower part of Kayak (Mksl) at same s Mkll. Less than 15 meters thick.

- Limestone, light gray, fossiliferous, contains large crinoid stems; some black chert with black mudstone in lower part of Kayak Shale. Less than 50 meters thick.

KEKIKTUK CONGLOMERATE

MERATE, UNDIVIDED - Divided into two sequences, Mkt-1 and Mkt-2, generally ault. To the north, Mkt-1 is thin, with deposition on Ordovician chert and argillite (unit relief on the underlying unconformity surface. Mkt-2 is thicker and exposed in the p area. Mississippian age.

MERATE, NORTHERN BELT - Quartz-chert breccia to pebble conglomerate and ray, often stained yellow-brown to rust-red, locally calcareous, fines upward; abrupt ness. Basal breccia is difficult to distinguish from massive chert of Romanzof chert. verlying siltstone and mudstone with abundant plant fossils. Generally less than 30

MERATE, SOUTHERN BELT - Quartz-chert pebble conglomerate, sandstone, and e includes white, gray, lavender and less common black chert pebbles and cobbles r. Matrix is light gray to lavender-gray, grading light gray to white quartzite, contains ed pyrite. Some channel geometry, tabular cross-beds, ripple cross-lamination, mud Jpward-fining intervals in an overall fining-upward succession. Deposited with low- Ulungarat Formation; grades abruptly upward into Kayak Shale in the southern part of ngues(?) with Kayak Shale in central part of the map area. Generally 40 to 130 m

MANGAQTAAQ FORMATION (new name)

lgal limestone with prominent oncoids, interbedded with sandstone and organic rich tone interbeds are cross-bedded and ripple cross-laminated. Interpreted to Ulungarat Formation; unconformably overlain by Kekiktuk Conglomerate. Age poorly evonian or Early Mississippian, based on plant fossils (locality 4) (S. Mamay, U.S. s. comm., 1989). Composite reference section localities B and C. 200 m thick.

Pebbly sandstone, subangular to angular chert pebbles; locally calcareous; locally e which internally contains dish structures.

ULUNGARAT FORMATION (new name)

TION, UNDIVIDED - Overall upward-thickening and -coarsening succession grading e and sandstone in lowest exposed strata upward to channelized conglomerate. brown. Base is a low-displacement thrust fault. Overlain by Mangaqtaaq Formation angle unconformity or by the Kekiktuk conglomerate on a low-angle unconformity. al members. The lowermost member is Middle Devonian (Eifelian, R. Blodgett, U.S. s. comm., 1992). The upper three members are bracketed between the Eifelian age Mississippian age of the unconformably overlying Kekiktuk Conglomerate. Reference

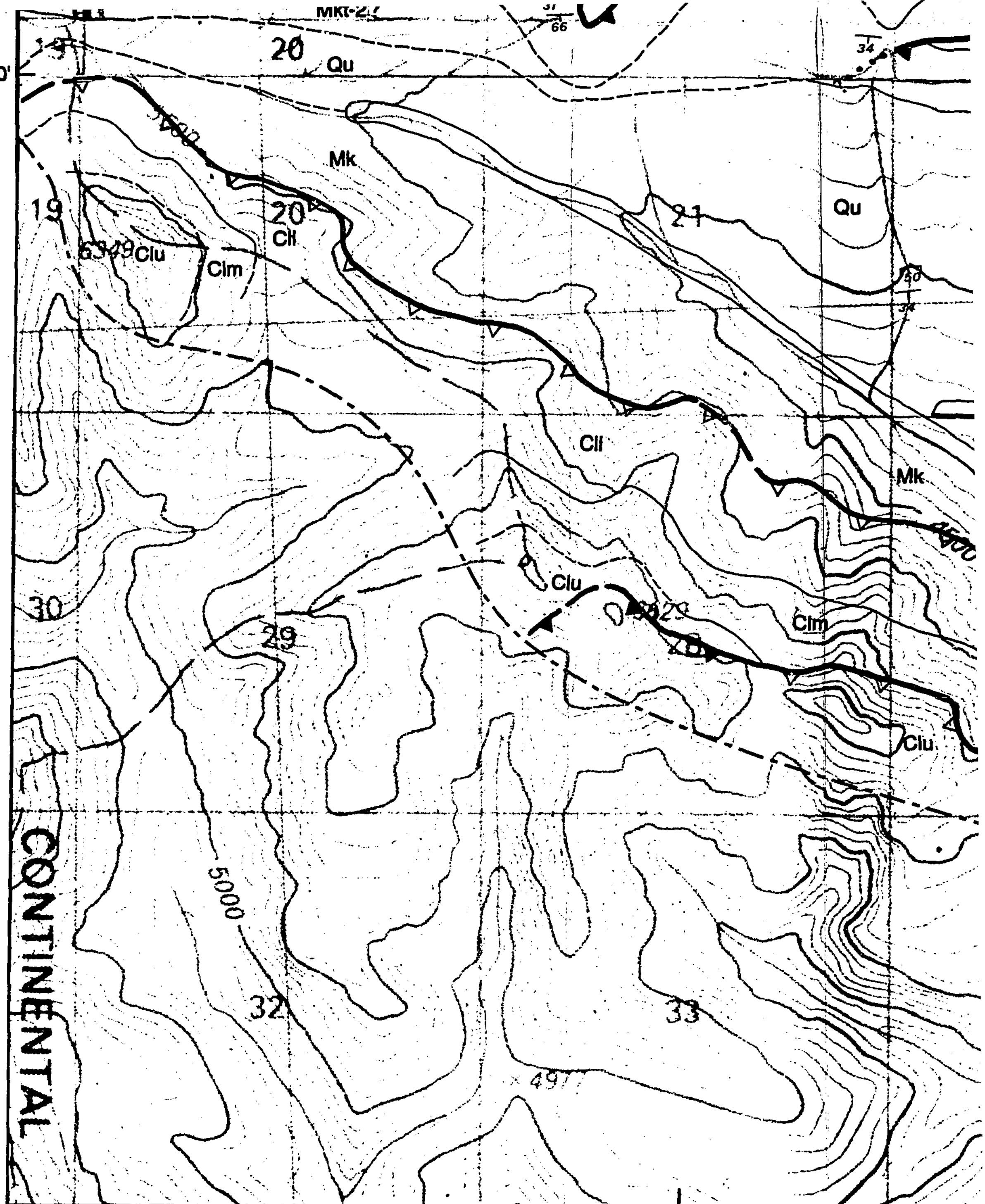
red and gray-green mottled mudstone and siltstone. Isolated, small, channelized to 50 m thick.

granule to pebble conglomerate and sandstone; sandstones weather gray, often o rust-red. Thick successions of amalgamated conglomeratic channel-fill deposits fill urfaces. Forms steep cliff. individual incised channel-fill successions are 20 to 30 m ide. Brown-red mudstone with interbedded thin sandstone beds underlie, are lateral orming conglomerates. Up to 110 m thick.

pebble conglomerate, sandstone, and siltstone in multiple, upward-fining sandstone ening siltstone beds. Sandstones weather gray, often stained yellow-brown to rust- l fills are 1 to 3 m thick. Rose-red and green-gray mottled mudstone. Plant fossils, Up to 110 m thick.

rd-thickening and -coarsening succession of mudstone, siltstone, and sandstone; half of assemblage is dominated by thin, amalgamated sandstone beds. Commonly liferous calcareous beds occur near the base. Forms irregular weathering steep e invertebrate fauna of Middle Devonian (Eifelian) age (locality 5). Up to 160 m thick.

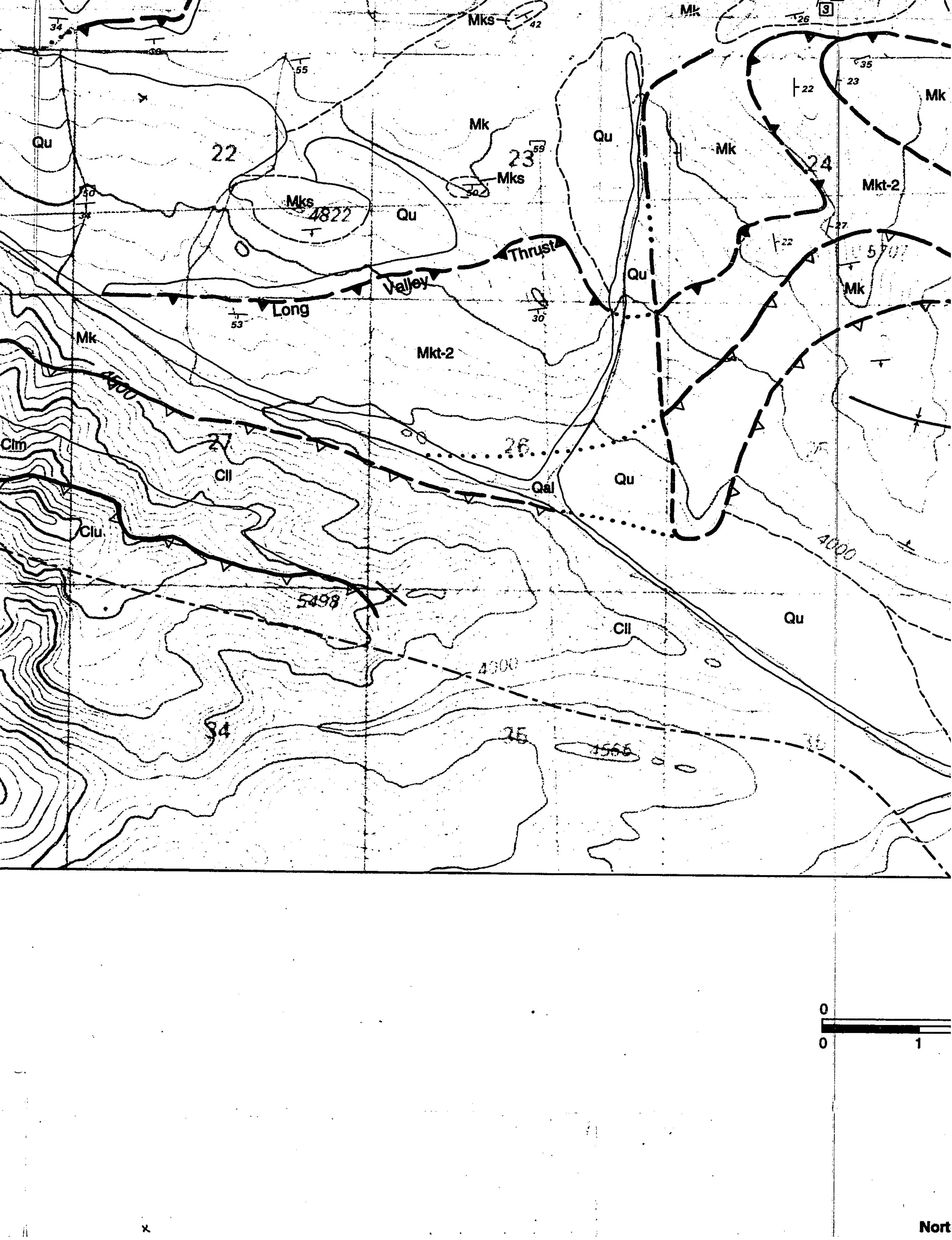
69°00'



143°20'

Base enlarged from U.S. Geological Survey
Demarcation Point (A-4) and Table Mountain
(D-4) Quadrangles, Provisional edition, 1983.

No vertical exaggeration.
Cross sections are schematic
and are not balanced.


Mks
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Valley
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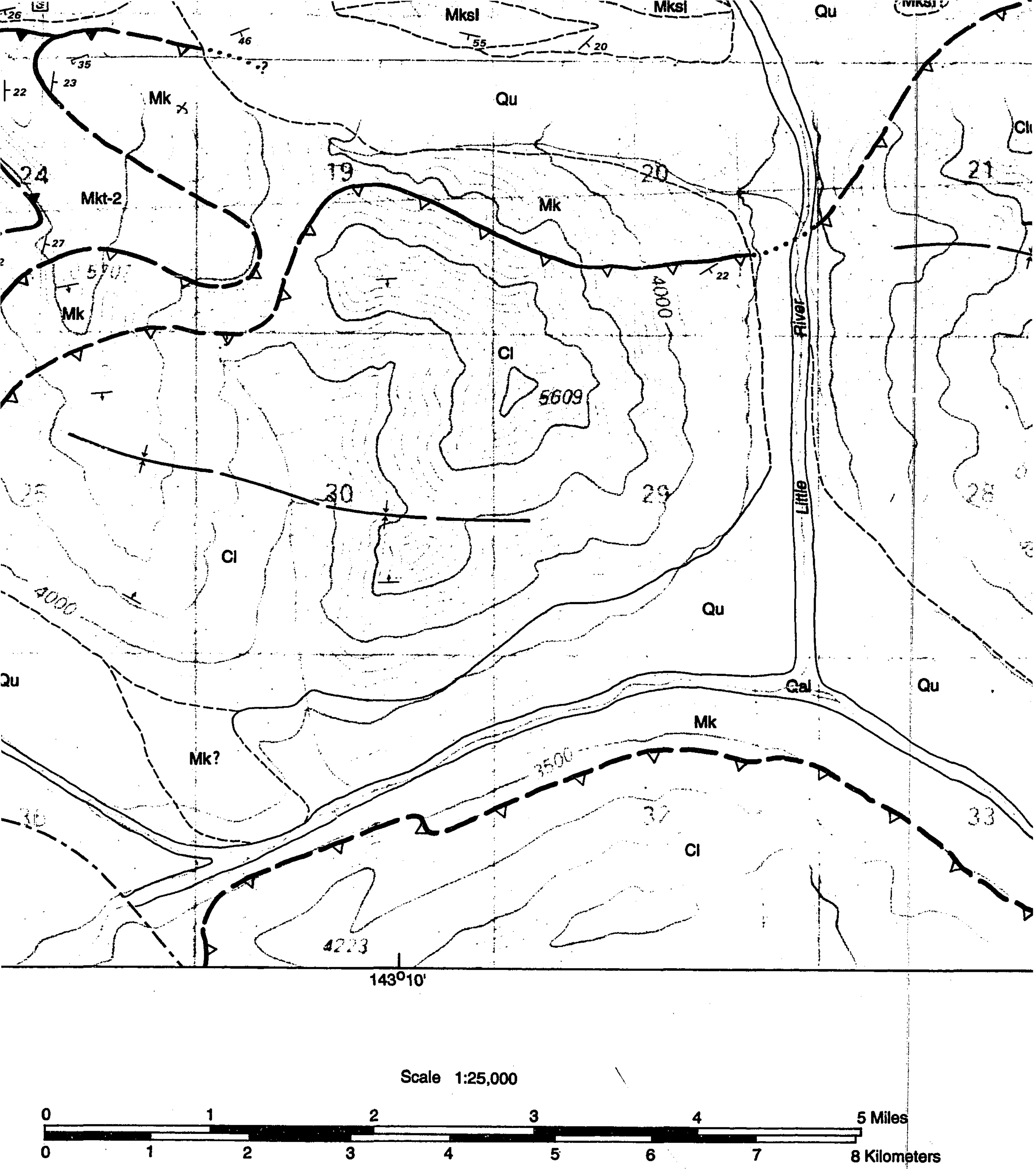
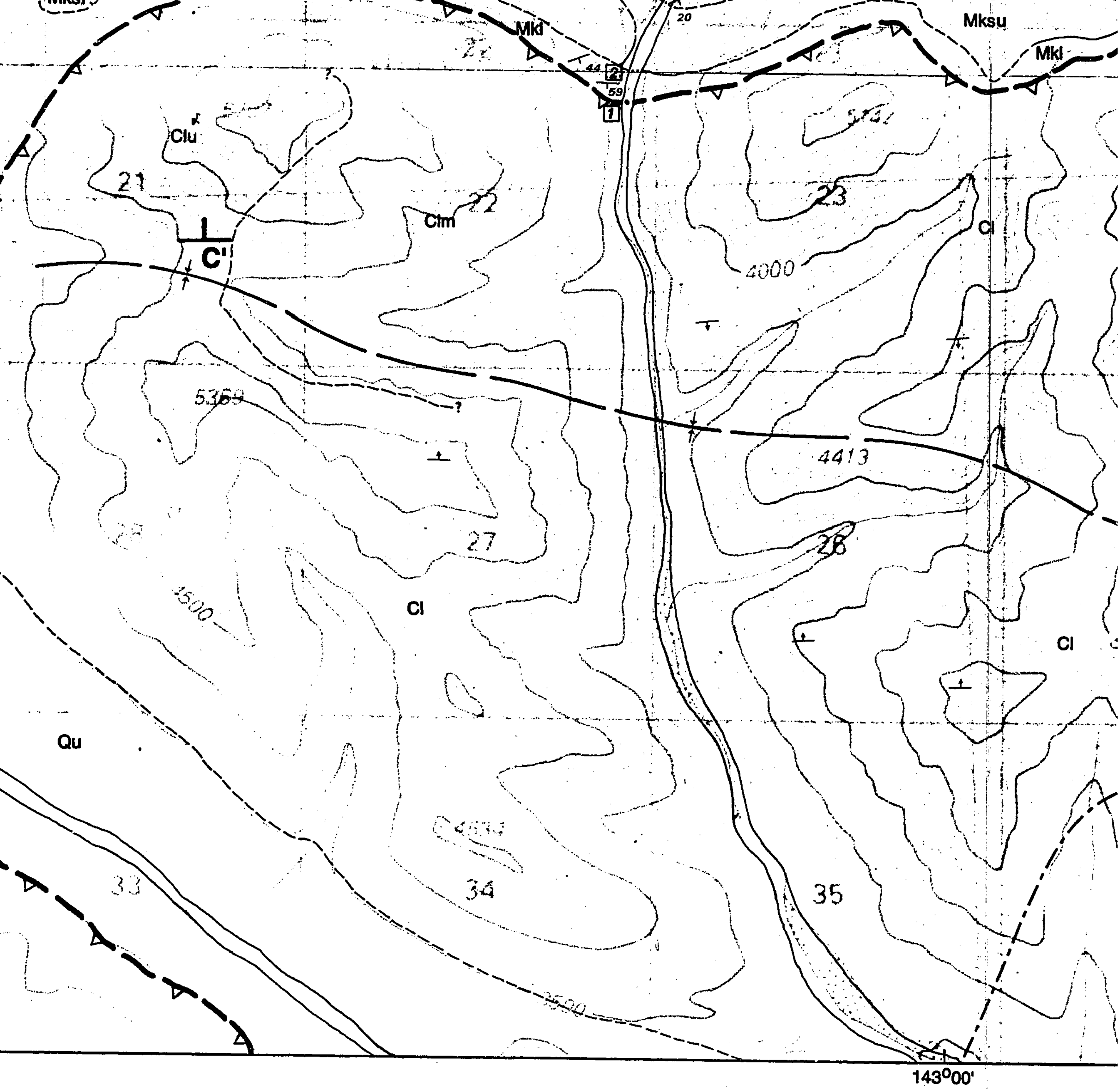


Scale 1:25,000

Contour Interval 100 Feet

North



Miles

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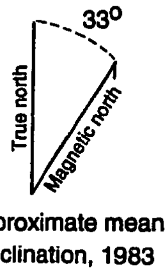
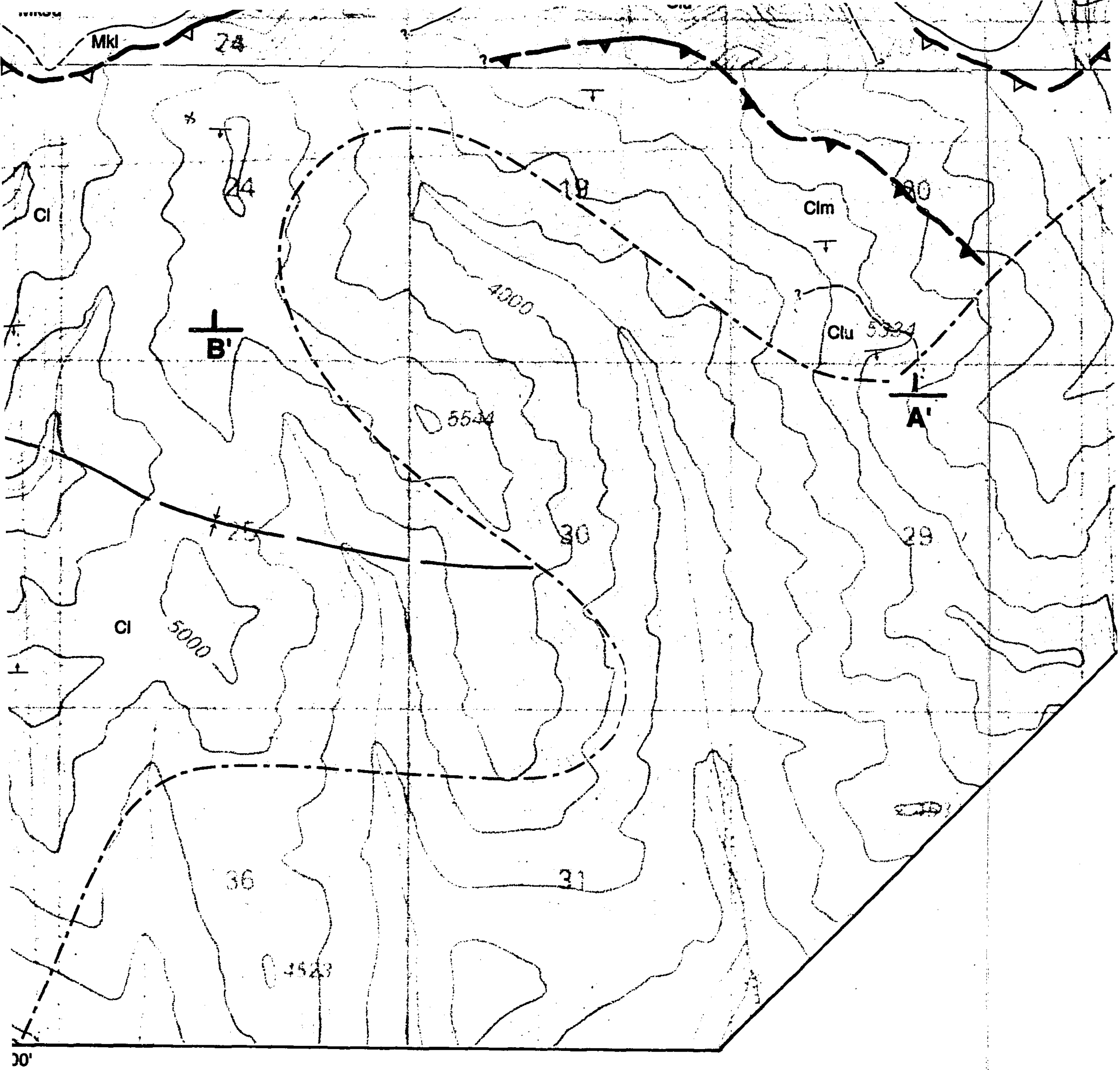


Approximate mean declination, 1983

South

North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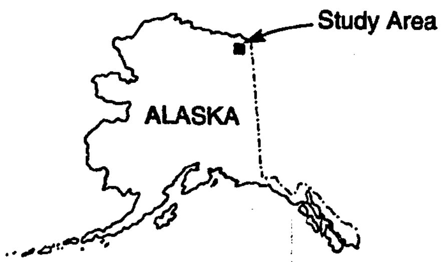
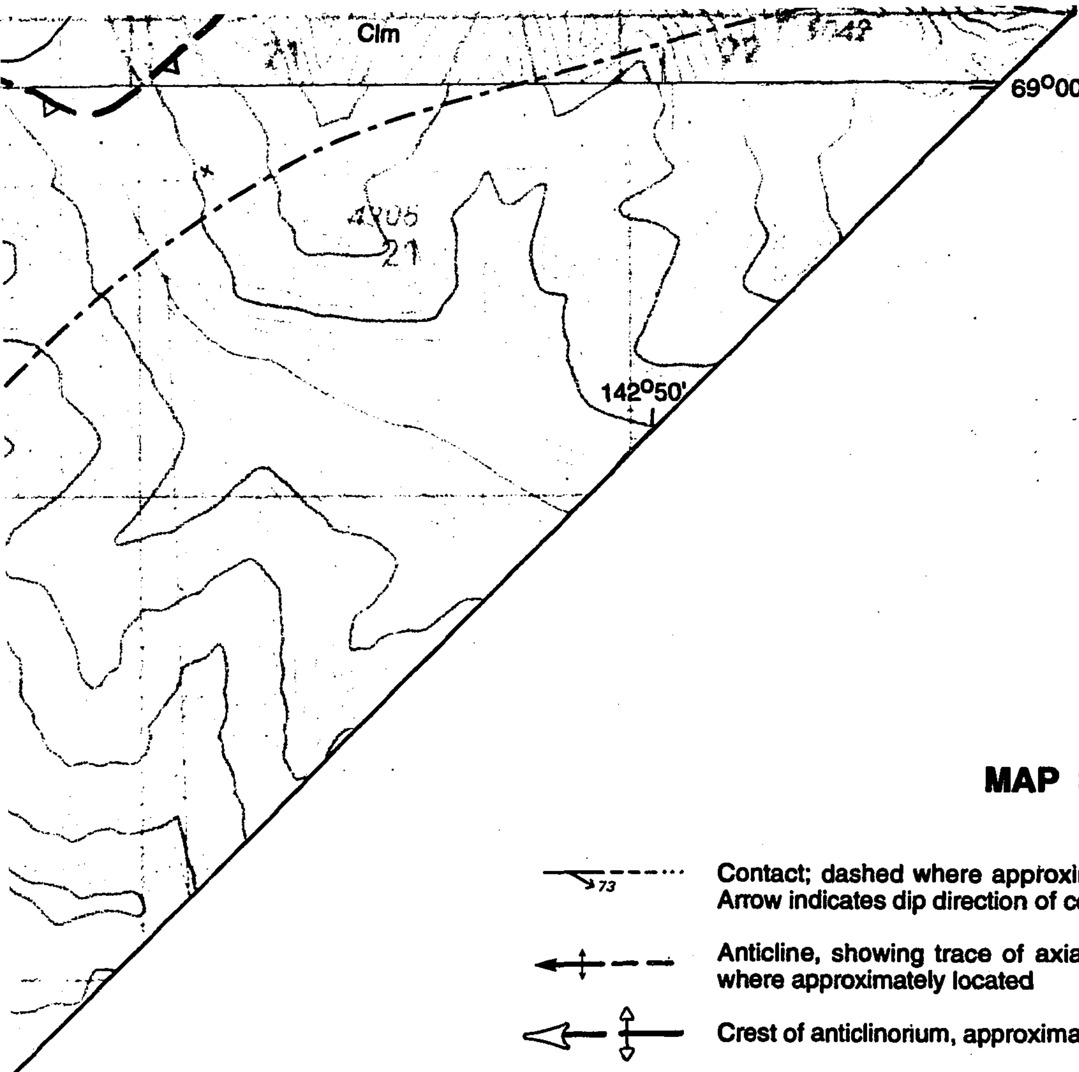

Study Area
ALASKA

North



mudcracks, 100

Dua (MEMBER A) · weathers gray; bioturbated; thi slopes. Shallow

Or ROMANZOF C 40% to 60% ph phyllite is uncle unit not expose duplicated by fc 1000 m. Form recovered from

c (CHERT UNIT) color; includes t crops out as thi gray phyllite; for

MAP SYMBOLS

Contact; dashed where approximately located, dotted where inferred Arrow indicates dip direction of contact

Anticline, showing trace of axial surface and plunge of axis; dashed where approximately located

Crest of anticlinorium, approximately located

Syncline, showing trace of axial surface and plunge of axis; dashed where approximately located

Overturned syncline, showing trace of axial surface and plunge of axis; dashed where approximately located

Thrust fault; dashed where approximately located, dotted where inferred; barbs on upper plate. Solid barbs indicate older-over-younger relationship; open barbs indicate younger-over-older relationship; alternating closed and open barbs indicate unknown age relationship. Number indicates measured dip of fault.

0-30 30-60 60-90 90 Fault, approximate dip indicated by tick marks.

Strike and dip of beds

Vertical beds

Overturned beds

Estimated dip.

Cleavage

C C' Line of cross section

Limit of mapping

Line of reference section

Fossil locality.

South

Dua (MEMBER A) - Upward-thickening and -coarsening succession of mudstone, siltstone, and sandstone; weathers gray; upper half of assemblage is dominated by thin, amalgamated sandstone beds. Commonly bioturbated; thin, fossiliferous calcareous beds occur near the base. Forms irregular weathering steep slopes. Shallow-marine invertebrate fauna of Middle Devonian (Eifelian) age (locality 5). Up to 160 m thick.

ROMANZOF CHERT (informal name)

Or ROMANZOF CHERT, UNDIVIDED - Structurally complex mixture of chert lenses in dark gray phyllite. Unit is 40% to 60% phyllite showing penetrative cleavage. Original depositional relationship between chert and phyllite is unclear. Phyllite forms recessive weathering intervals generally less than 100 m thick. Base of unit not exposed in map area. Top of unit is major angular unconformity. Chert and phyllite structurally duplicated by folds and imbricate thrust faults. Thickness unknown, but structural thickness greater than 1000 m. Forms high mountains in northwest part of map area. Ordovician age based on graptolites recovered from presumably equivalent rocks along strike to the southwest (Moore and Churkin, 1984).

c (CHERT UNIT) - Chert, massive- to medium-bedded; black, mottled gray, white, and less common raspberry color; includes black ribbon chert showing pinch and swell; tight to isoclinal folds and refolded folds. Chert crops out as thick resistant intervals up to 100's of m thick; interbedded or structurally interleaved with dark gray phyllite; forms long linear outcrops. Chert units locally differentiated.

CORRELATION OF MAP UNITS

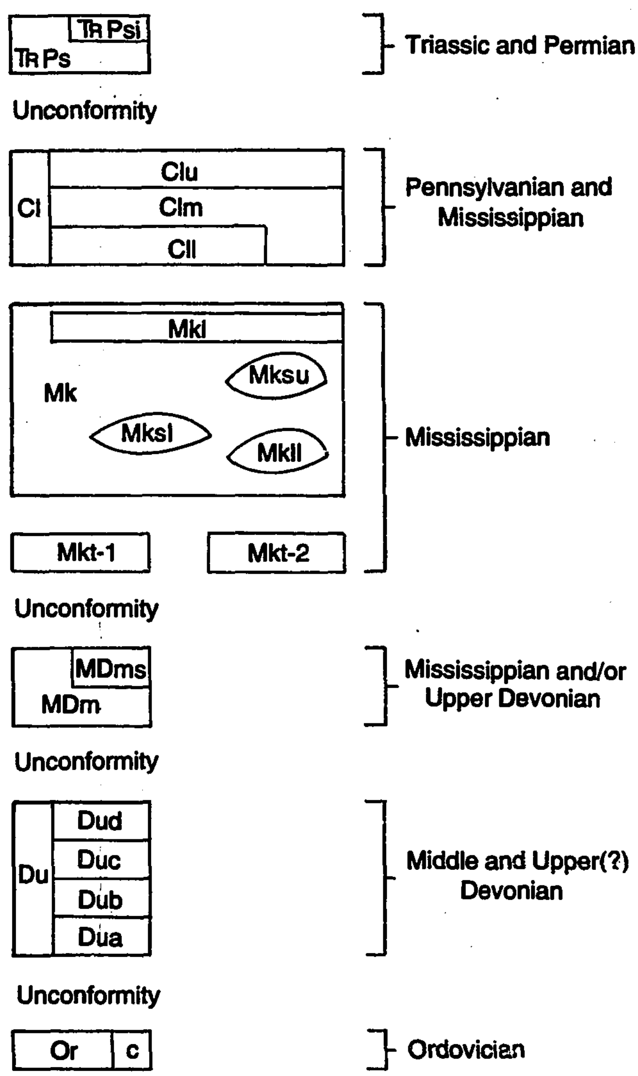
where inferred

of axis; dashed

of axis; dashed

l plunge of axis;

, dotted where
er-over-younger
ər relationship;
ıge relationship.



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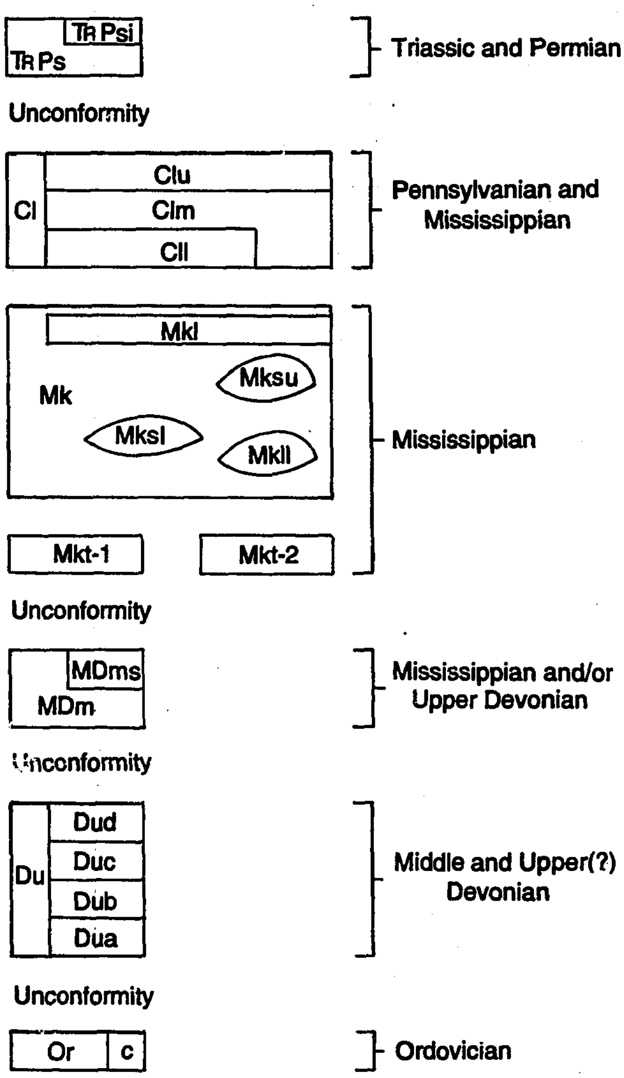
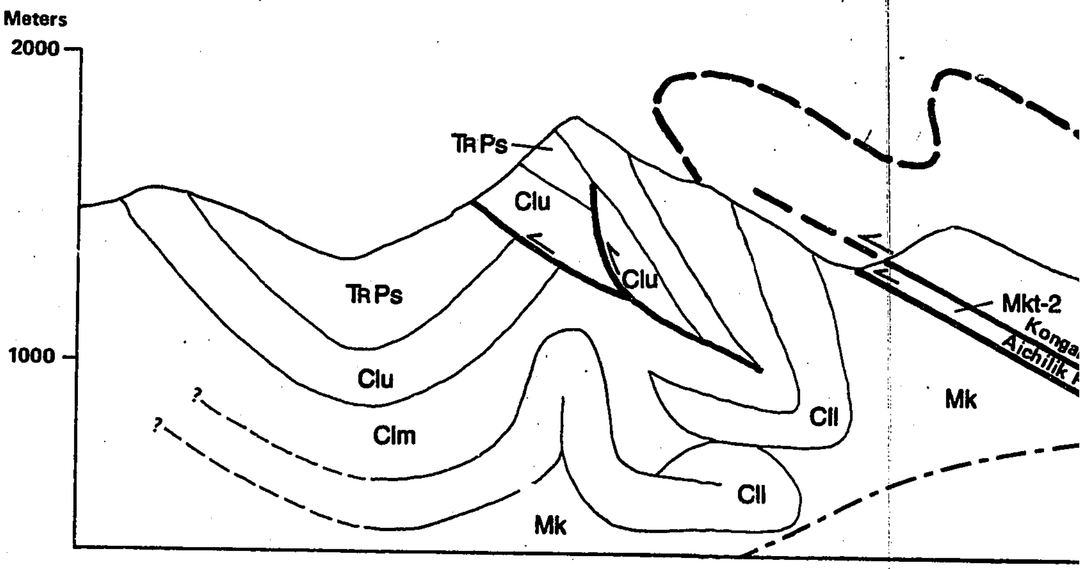
CORRELATION OF MAP UNITS



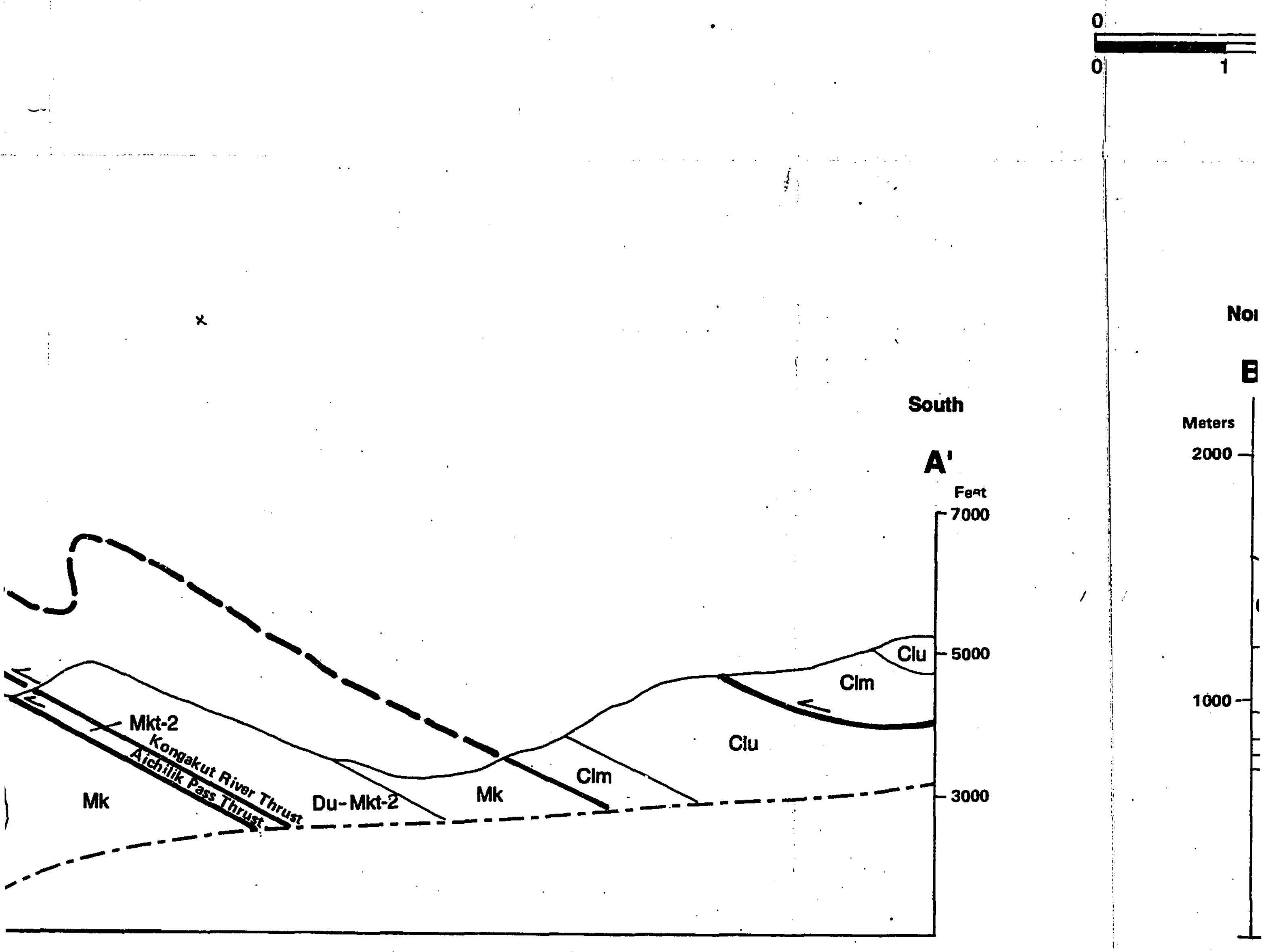
No vertical exaggeration.
Cross sections are schematic
and are not balanced.

North

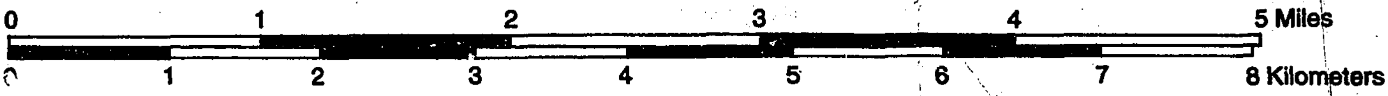
A



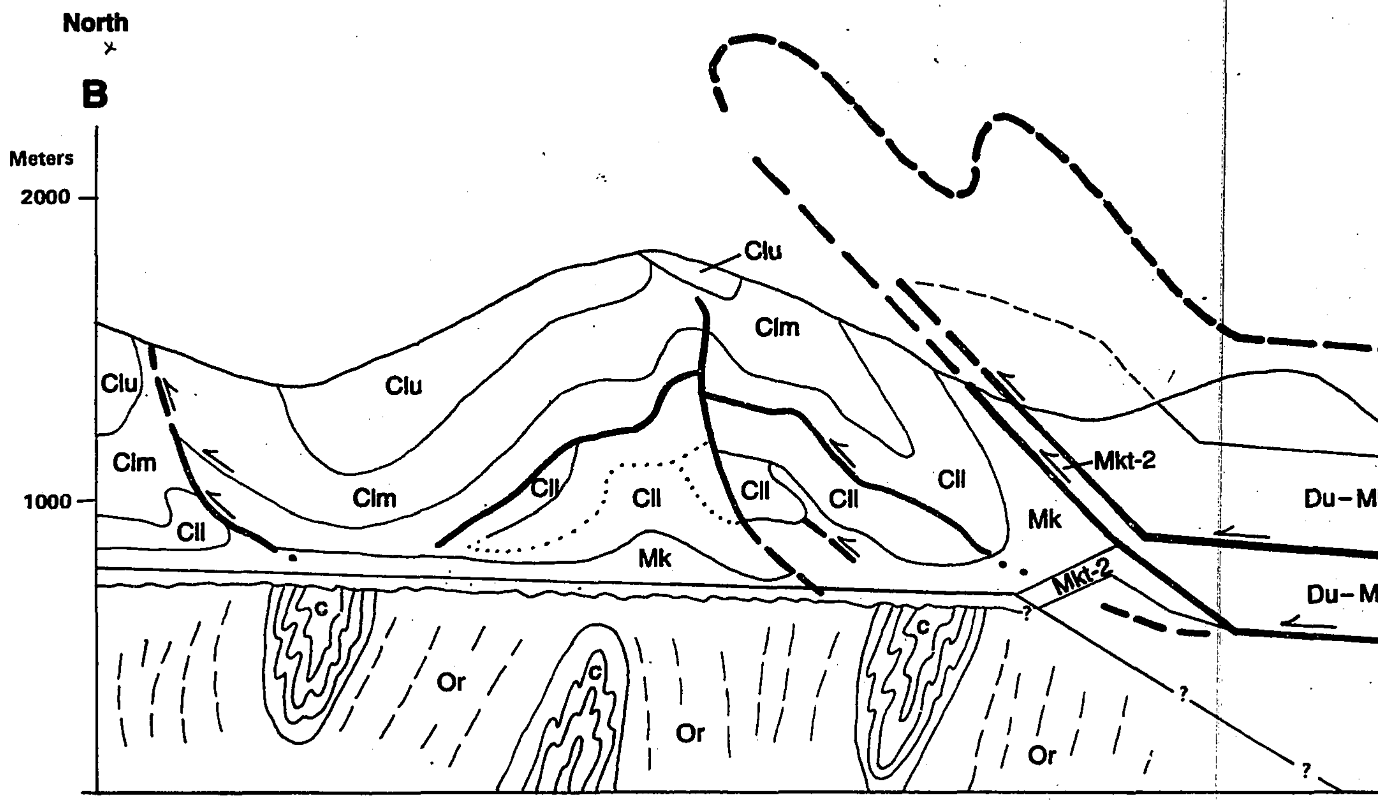
HEADWATERS OF THE KONGA



KONGAKUT AND AICHILIK RIVERS DEMARCATI



Contour Interval 100 Feet



GEOLOGIC MAP AND C

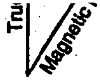
MARCATION POINT (A-4) AND TABLE MOUNTA

By A.V. Ander

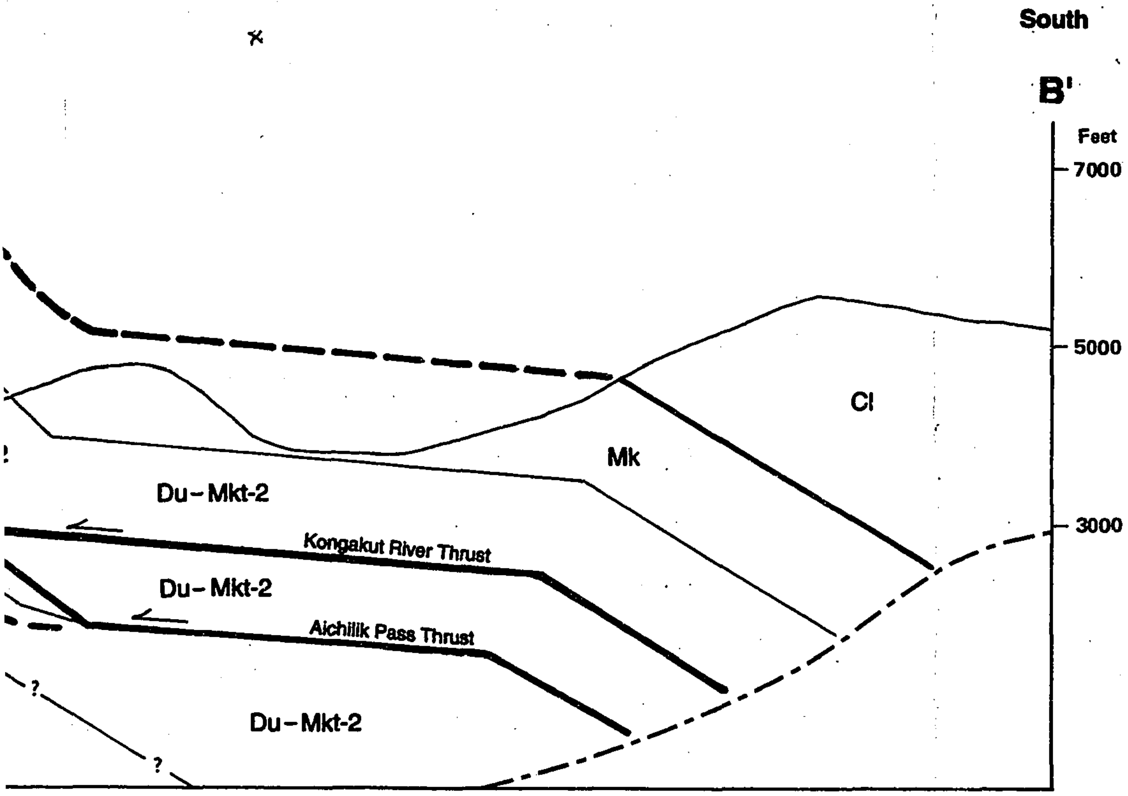
1993

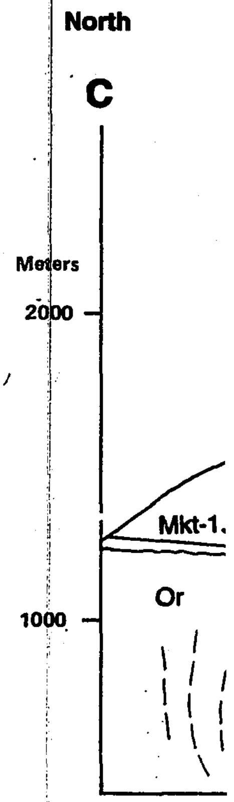
5 Miles

3 Kilometers



Approximate mean declination, 1983



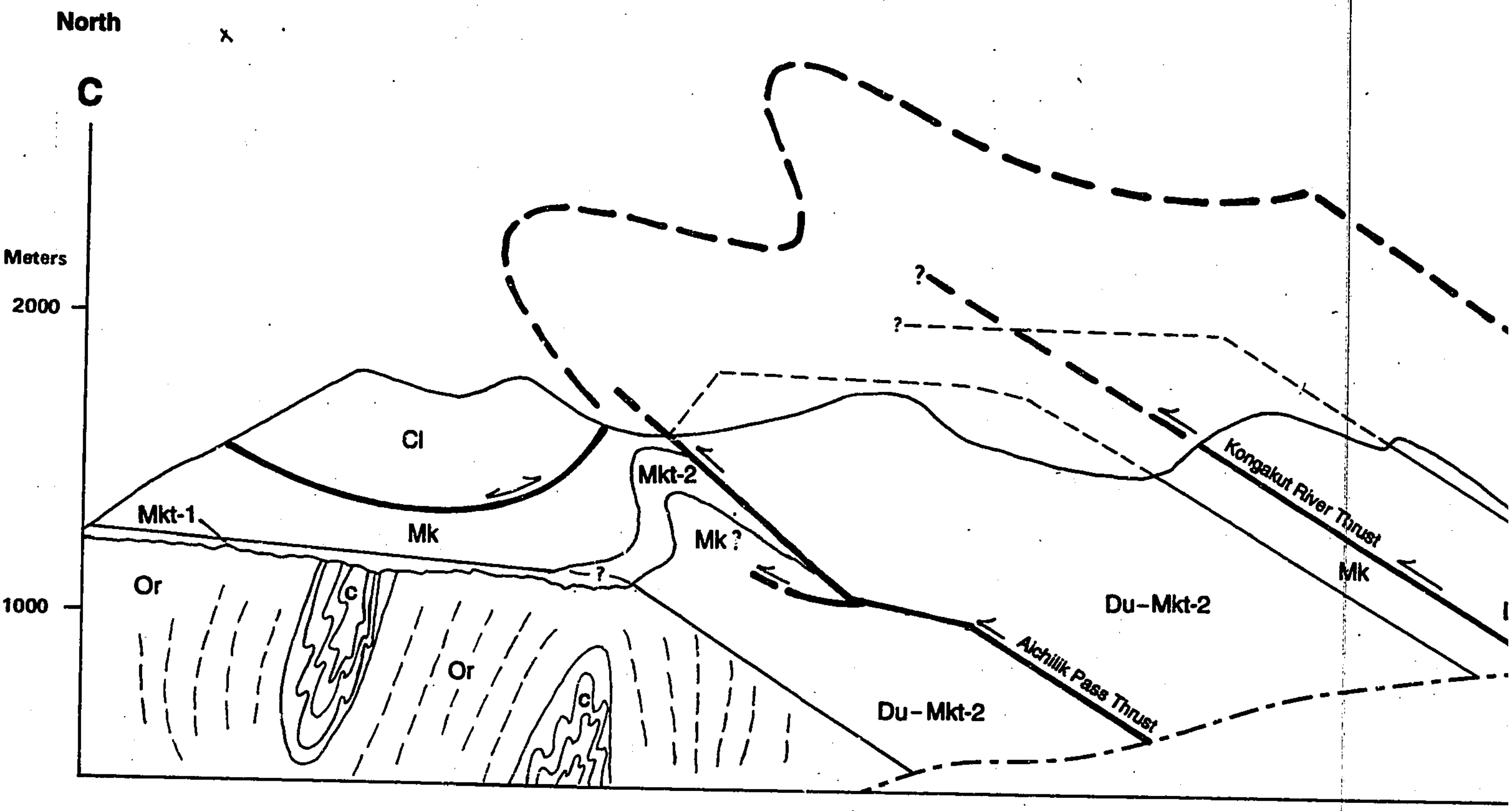


AND CROSS SECTIONS

IOUNTAIN (D-4) QUADRANGLES EASTERN BRC

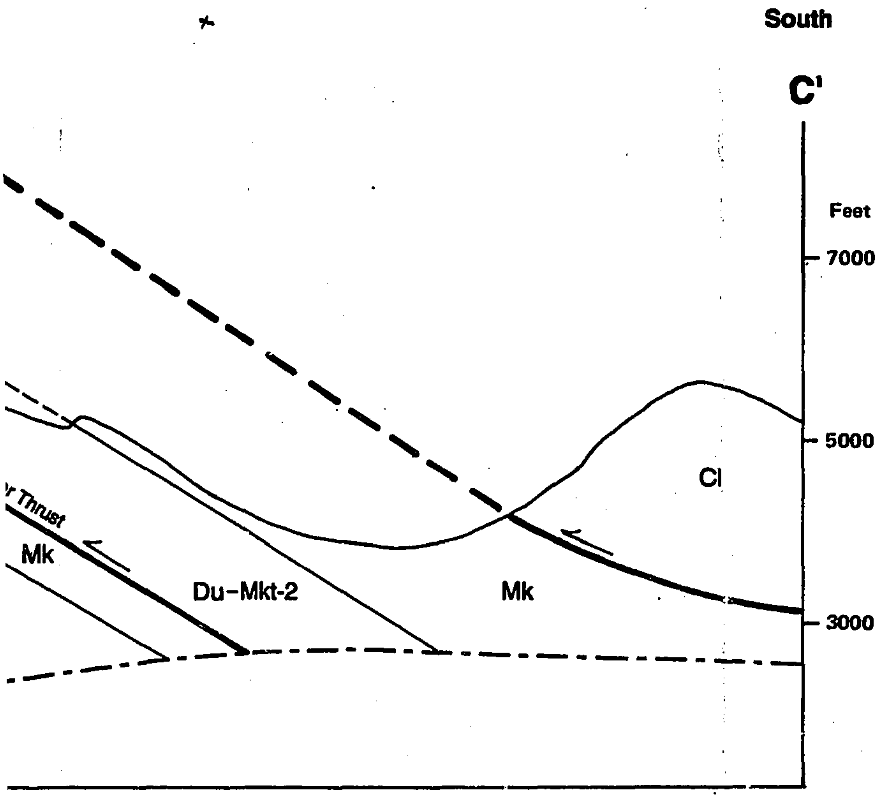
.V. Anderson

1993



N BROOKS RANGE, ARCTIC NATIONAL WILDLI

73	Cleavage
C ⊢ ⊣ C'	Line of cross section
	Limit of mapping
Ⓐ	Line of reference section
3	Fossil locality.



VILDLIFE REFUGE, ALASKA

Du: Dud, Duc, Dub, Dua — Middle and Upper(?) Devonian

Unconformity

Or | c — Ordovician

THIS REPORT HAS NOT BEEN REVIEWED FOR TECHNICAL CONTENT (EXCEPT AS NOTED IN TEXT) OR FOR CONFORMITY TO THE EDITORIAL STANDARDS OF DGGS.

Du	Dud	Middle and Upper(?) Devonian
	Duc	
	Dub	
	Dua	

Unconformity

Or	c	Ordovician

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